Biomechanical perspectives on classical ballet technique and implications for teaching practice

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Publication Date:
2012

DOI:
https://doi.org/10.26190/unsworks/15654

UNSW

BIOMECHANICAL PERSPECTIVES ON CLASSICAL BALLET TECHNIQUE AND IMPLICATIONS FOR TEACHING PRACTICE

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A thesis in fulfilment of the requirements for the degree of Doctor of Philosophy

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Sydney, Australia

September 2012

PLEASE TYPE

THE UNIVERSITY OF NEW SOUTH WALES
Thesis/Dissertation Sheet

Surname or Family name: Ward

First name: Rachel

Other name/s: Evelyn

Abbreviation for degree as given in the University calendar: PhD

School: School of Risk and Safety Sciences

Faculty: Faculty of Science

Title: Biomechanical perspectives on classical ballet technique and implications for teaching practice

Abstract 350 words maximum: (PLEASE TYPE)

Classical ballet is an art form well known for its very distinct and precise movement style. A review of relevant literature led to the identification of four fundamental biomechanical principles of classical ballet technique: "alignment"; "placement"; "turnout", and "extension".

The capacity to execute technique correctly is a fundamental prerequisite for a successful career as a professional classical ballet dancer. Given this, the averaged kinematic data from professional ballet dancers performing core ballet steps provides a practical biomechanical benchmark of "correct" technique. Three-dimensional (3D) full-body motion analysis of 14 ballet steps was used to compare the performance of professional classical ballet dancers (N=12) with that of non-professional ballet dancers (N=14), and to investigate the level of agreement between practical execution of the steps with the theoretical ideals. Professional dancers did demonstrate kinematic variables relating to "turnout" and "extension" in agreement with the theoretical principles, however some deviations between practice and theory were observed in the areas of "alignment" and "placement". This result has implications for the teaching methods currently used in classical ballet instruction.

Having established the practical kinematic principles of "correct" classical ballet technique, the accuracy of qualitative analysis of "correct" and "incorrect" ballet technique was investigated with respect to 'experience' in classical ballet instruction. Teachers' qualitative responses were compared to quantitative data obtained from 3D motion analysis. A positive relationship between years of teaching experience and accuracy of qualitative analysis was demonstrated, however even the most experienced teachers only achieved moderate accuracy. Improvement in accuracy with increasing experience appeared to be slow, and plateaued after 10 years. These observations are important in terms of developing curricula and teaching programs for dance teachers.

Given the relatively low accuracy of qualitative analysis demonstrated by experienced teachers, a quantitative assessment tool was developed in which data from individual dancers were compared to the practical "gold standard" of technique, as demonstrated by professional ballet dancers. Analyses were conducted to determine the minimum number and appropriate combination of ballet steps for inclusion in the assessment tool that would most efficiently enable the evaluation of dancers against the four fundamental principles of classical ballet technique.

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ACKNOWLEDGEMENTS

There are many people who contributed to the completion of this project. To each of them I am extremely grateful.

Thank you to my supervisors Associate Professor Andrew McIntosh and Dr John Mullins. Andrew, I sincerely thank you for guiding and assisting me to completion of this project. You have been a constant source of support and encouragement, often amidst times of uncertainty about the future of the equipment, the laboratory, and the school. Thank you for helping me stay focused on the task at hand during these difficult and distracting times. My gratitude to you also extends beyond completion of this project. Your mentorship during the years prior to commencement of his project was invaluable. You laid the foundations for my academic career, instilling me with confidence, motivation, enjoyment and appreciation of biomechanics, and the necessary skills for a rewarding future. I am grateful for the interest you have always shown towards my passion for dance, and for your constant belief in my abilities.

John, your input to this project has been truly invaluable and is deeply appreciated. Thank you for bringing your expert perspectives on dance education to the project, and for ensuring that the project's relevance and practical application remained a priority. Thank you for many interesting and thought provoking conversations, and for your constant availability and accessibility. I have enjoyed working with you, and I sincerely respect and value the supervision you have provided.

To my esteemed friend and colleague, Ms Kim Traynor, thank you for sharing your immense understanding of classical ballet with me and with this project. I am grateful for your unceasing interest, encouragement, and enthusiasm. You are a source of great inspiration for me and for the hundreds of ballet students who have the privilege of your tutelage. The knowledge and skill you bring to the dance teaching profession are unsurpassed. I hope many students will continue to experience your brilliance.

I also extend heartfelt thanks to all the dancers and dance teachers who volunteered to participate in this project. I appreciate your time and interest, and share in your commitment to and passion for dance.

To Patrick, thank you for your unwavering love and support during these past few years. I am truly grateful for the steadfast encouragement, the delicious meals, and the comic relief, all provided at exactly the right moment. Thank you for riding out the difficult times with me, and for your incredible loyalty and patience.

Finally, to my “darling” mum Lynne, to whom I owe everything. You have provided me with so many opportunities, and for this I am eternally grateful. Thank you for making it possible for me to pursue and fulfil my dance ambitions, and for also inspiring me towards academic achievement. I appreciate your love and support more than I am able to articulate. My love for you is infinite. Thank you.

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INTRODUCTION

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1.1 Introduction

The art form of classical ballet is well known for its very distinct and precise movement style. The professional classical ballet dancer spends many years diligently learning, practising and perfecting their skills. From a young age dancers undergo regular training sessions, more commonly referred to as “classes”, in an effort to acquire the very particular movement patterns and aesthetics that characterise the dance style. Typically, a young dancer will spend a minimum of 8 years in a demanding training program if they are to gain the skills necessary to advance to a professional level. From the age of about 10 years, young dancers aspiring to a professional career in classical ballet will undertake at least 3 ninety minute classes per week. If, when they reach 14 or 15 years of age, they are still serious about pursuing this passion, then it is not uncommon to enter into a full-time training program for the final 3 or 4 years of training. This level of training usually involves multiple classes per day.

Throughout this training process, it is the role and responsibility of the ballet instructor to help the aspiring young dancer learn what constitutes correct classical ballet technique, and how to execute it. Unlike many other physical activities, most sporting pursuits for example, dance does not have an obvious measurable external parameter to assess a dancer’s level of competency. In the sporting arena, success can be measured objectively using variables such as running speed, jump height, or the number of baskets, goals or tries scored. The execution of correct classical ballet technique however is determined purely by the movement patterns and shapes the dancer makes with his or her body. This may be the movement of the upper and lower limbs in relation to the torso, or the movement trajectories of the whole body in the classroom or on the stage.

Although it is widely understood that other characteristics also influence the perceived merits of a dancer, without correct and competent technique a classical ballet dancer will not gain employment in a professional capacity. Aspects such as: musicality; projection of personality and charisma; body shape and proportions; and the interpretive and artistic abilities; all influence an audience member's opinion of the appeal of a classical ballet dancer. However, it remains the execution of correct technique that is the fundamental prerequisite for a successful professional classical ballet career, and so it is essential that these fundamental technical principles be clearly understood and meticulously mastered.

Without clear objective measures of skill competency, the young dancer in training must rely on the movement analysis skills of their instructor in order to attain correct technique. That is, they must rely on their teacher to have a thorough understanding of what constitutes correct classical ballet technique, trust that their teacher is able to clearly see how they are moving, and then be able to communicate effectively the details of any corrections or alterations that are required. "Basic to making effective corrections is the teacher's ability to *see* what is wrong and *know* what will help" (Schlaich and DuPont, 1993, p53).

Outstanding teachers of classical ballet are known to possess many different attributes, which not only include mastery of the technical materials of the class, but also various personal qualities and values. Schlaich and DuPont (1993, p9-10) identify some of the necessary characteristics of the expert dance teacher as being: "a love of movement and teaching; a physical knowledge of movement; a knowledge of the mechanics of the body; interest in people; an ability to create a positive atmosphere for learning; ability to plan a purposeful class; musical knowledge; ability to teach dancing with artistry; a trained eye, and an ability to communicate clearly". Although these many different qualities are required for effective dance teaching practice, a specific aim of this research thesis is to investigate the characteristics and accuracy levels of the "trained eye" of classical ballet teachers. Schlaich and DuPont (1993, p2) describe someone with a "trained eye" as "knowing what to look for, having the ability to spot problems, and having an awareness to detail". It is therefore essential that effective teachers of classical ballet technique have the ability to perceive the difference between skilled and unskilled movement. A considerable proportion of professional classical ballet teachers would have themselves undergone many years of classical ballet training, some of them would have achieved a competent and strong enough technique, together with the necessary artistic attributes, to gain employment as a professional ballet dancer. Regardless of their eventual employment status within the dance profession, most classical ballet teachers have spent many years, usually more than a decade, carefully watching the execution of classical ballet technique. As students they would have watched demonstrations given by their teachers, and throughout their lifetime would have attended many live professional classical ballet performances and watched numerous dance films and videos. One would expect therefore that all professional teachers of classical ballet should easily be able to differentiate between a skilled and unskilled ballet dancer. But what are these parameters or characteristics of the classical ballet movement vocabulary that one looks for in order to identify a technically skilled ballet dancer, and just how good are ballet teachers at perceiving them? Identification and measurement of the fundamental principles that define the classical ballet technique, and the characteristics of the “trained eye” will be the focal topics of this research project.

1.2 Aims of the Thesis

This research project initially aims to identify the fundamental theories and basic biomechanical principle of correct classical ballet technique. To this end, a number of highly regarded classical ballet texts outlining the theories and principles of the technique will be examined. From this review of the literature a succinct list of theoretical principles will be compiled. These principles will be described in terms of concise measurable biomechanical parameters. Having identified these theoretical principles, and their corresponding biomechanical variables, a sample of professional and non-professional ballet dancers will then be recruited to the study. In order to assess the level of agreement between what is considered to be theoretically correct execution of ballet technique, as outlined in the dance literature, and the practical execution of classical ballet technique, both groups will perform the same set of basic classical ballet movements while undergoing three-dimensional (3D) motion analysis and video analysis.

The analysis of human movement is a vastly complex field of research, encompassing a variety of important components. In addition to joint movement patterns, motor control and coordination (*i.e.* movement cause-effect & inter-segmental relationships) are some of the other interesting areas of human movement research that are also relevant to the execution of classical ballet technique. However, it should be noted that the focus of the current research project will be constrained to investigation of the actual movement patterns (*i.e.* kinematic data) of professional and non-professional ballet dancers, without consideration of the muscle activation patterns (*i.e.* electromyography data), or joint forces and moments (*i.e.* kinetic data) that control the resultant joint movements. While it is understood that multiple motor control strategies may lead to a similar movement outcome, this study will not attempt to perform any analyses or reach any conclusions related to the motor control strategies employed by the participating dancers.

Kinematic difference between the two groups will be compared to determine the degree to which professional ballet dancers execute classical ballet technique relative to the theoretically “correct” principles compared to non-professional dancers. The biomechanical characteristics of classical ballet demonstrated by the professional ballet dancers will be examined to determine if they are in accordance with the theoretical principles discussed in the review of the classical ballet literature.

Given that the capacity to execute ballet technique correctly is a fundamental prerequisite for a successful career as a professional classical ballet dancer, the kinematic data obtained from the professional dancers can therefore be considered to be a practical biomechanical benchmark of “correct” technique. Thus, having established the practical kinematic principles of “correct” classical ballet technique, the next section of the study will investigate the accuracy with which ballet teachers can visually assess and identify whether or not a ballet dancer is executing “correct” technique. A group of professional classical ballet teachers and a group of student classical ballet teachers will be recruited to the study. The participating teachers will watch a number of videos of dancers performing standard classical ballet steps. These videos will correspond to 3D motion analysis data obtained during the first part of the study. The teachers will be asked to respond to specific questions about the dancers’ technical execution of the steps. These responses (*i.e.* qualitative assessments) will be compared to the quantitative data obtained from the 3D motion analysis. From these results it will be possible to determine the accuracy with which the professional and student teachers identify certain kinematic characteristics of classical ballet technique.

Upon consideration of the data obtained from the first two analysis phases of the thesis, a tool for quantitative assessment of classical ballet technique will be developed. Given the high expense, and long data collection and processing times typically associated with 3D quantitative analysis, an assessment tool that is designed for routine or regular use, would be useful, however it would need to be designed with maximum efficiency as a key consideration. To this end, the final aim of the project is to develop a quantitative assessment tool consisting of the minimum number of kinematic variables and the minimum number and appropriate combination of ballet steps that can effectively detect deviations in the kinematic variables that relate to the fundamental principles of classical ballet technique.

Although this project is focusing purely on the art of classical ballet, a highly specialised movement technique, the questions addressed within the study, and the conclusions reached, may be of interest to other dance styles and other physical activities. All movement instructors or coaches need to have a basic knowledge of the fundamental biomechanical principles on which their movement discipline is based, and must rely heavily on their qualitative analysis skills through use of observation. Thus, relevant content knowledge and a "well trained eye" are crucial factors that ideally should be developed by all physical education teachers and coaches. The results of the current study therefore have the potential to not only assist dance instructors within the classical ballet community, but can also provide an example of how similar research can be applied to other dance genres and other movement disciplines. Accurate observation of dance and sporting movements may save students from the frustrations of endless trial and error in their attempts to acquire new skills, and reduce the risk of fatigue and physical injury. The question of how accurately physical education instructors observe skilled movement is therefore of great importance to all pursuits involving skilled physical activity. An instructor's ability to *see* what is wrong is the first step towards effectively assisting a student to improve their physical technique, and consequently their chance of achieving excellence in their chosen discipline. In addition, the methods applied in the development of the quantitative assessment tool for classical ballet could potentially be used for design of a similar tool for other dance genres or movement disciplines. Thus, the results from this thesis may be also be useful and applicable beyond the field of classical ballet instruction

1.3 Structure of the Thesis

The following section provides an overview of the thesis, giving a brief outline of the contents of each chapter:

Chapter 2 - Literature Review

This chapter starts by examining the historical context that shaped the development and refinement of classical ballet technique. Review of dance literature dating from 1820 through to 2010 enables identification of a list of fundamental biomechanical principles that succinctly characterise the technical elements of classical ballet. Review of the extent to which instrumented quantitative biomechanical analysis has been conducted on theatrical dance styles, and reported in academic literature, forms the basis for the next section of the literature review. Aims, instrumentation techniques, and protocols for scientific studies involving quantitative analysis of various dance genres are discussed. Additional focus is given to quantitative analysis of classical ballet technique. The chapter concludes with a discussion of qualitative analysis of human movement. Qualitative analysis is defined, its application in various contexts is discussed, and a review of scientific studies that have investigated accuracy of qualitative analysis is presented. Factors that affect accuracy of qualitative analysis of human movement are identified and summarised.

Chapter 3 - Comparison of Theoretical and Practical Execution of Classical Ballet Technique

This chapter presents a biomechanical analysis of classical ballet technique. Having identified the fundamental theoretical principles of classical ballet technique, 3D motion analysis of professional and non-professional ballet dancers performing core classical ballet steps is conducted. The aim is to assess the level of agreement between practical execution of classical ballet technique with the theoretical ideals presented in the dance literature. The methods used, results obtained, and conclusions reached are reported.

Chapter 4 - Accuracy of Qualitative Analysis of Classical Ballet Technique

This chapter investigates the qualitative analysis abilities of professional and student ballet teachers. The accuracy of qualitative analysis of "correct" and "incorrect" ballet technique is investigated with respect to 'experience' in classical ballet instruction. Teachers' qualitative responses are compared to quantitative data obtained from 3D motion analysis. The methods used, results obtained, and conclusions reached are reported.

Chapter 5 - Development of a Quantitative Tool for Assessment of Classical Ballet Technique

This chapter describes the development of a quantitative tool for assessment of classical ballet technique. The aim is to determine the minimum number and appropriate combination of ballet steps for inclusion in the assessment tool, so that redundancy of steps is identified and eliminated. Through this process, the quantitative assessment tool that most efficiently evaluates dancers against the four fundamental principles of classical ballet technique is developed. Methods and results of the analyses, and the final version of the assessment tool are presented.

Chapter 6 - General Conclusions and Implications

This chapter summarises and discusses the main findings from Chapters 2 to 5. General and specific conclusions are discussed, with focus given to their implications on dance teaching practice. Potential future directions for this line of research are also outlined.

CHAPTER 2

LITERATURE REVIEW

CHAPTER 2
LITERATURE REVIEW

2.1 Foundations of Classical Ballet Technique

2.1.1 Introduction

In order for movement instructors to be effective in teaching any movement discipline or art form, it is imperative that they possess a thorough knowledge and understanding of the principles on which the movement form is based, and thus an internal image of the desired movement response. For ballet teachers, this knowledge is typically acquired through their training as dance students, and is perhaps further developed throughout a professional performance career. In some cases, additional knowledge of theoretical aspects of the discipline is acquired through completion of teacher training programs. Whether it is through practical experience of the movement form, or through teacher training programs, it is expected that classical ballet teachers fully understand the fundamental principles of the "technique" of the art form. The term *technique* is used widely in relation to skilled movement activities, but it is rarely defined. It is implicit in the general understanding of technique, that if a skill is performed with a "good" technique, rather than a "poor" technique, performance will be better (Lee, 2002, p814). Berardi (2005, p77) states that "good 'technique', rather than luck or chance, allows a dancer to balance at will, pirouette quickly, perform with precision, and appear graceful". It appears that those who use the word regularly (*e.g.* teachers, coaches, researchers, writers) presume that their audience has an understanding of the term, however this may not necessarily be the case. The term "technique" will therefore be defined here.

A general definition of technique is "a way of carrying out a particular task" (Oxford Online Dictionary, 2011). Sport-related definitions of technique include: "a pattern of movement which is technically appropriate for a particular skill, and which is integral to that skill" (Kent, 1994, p443); "the pattern and sequence of movements that athletes use to perform a skill" (Carr, 1997, p5) and, more complexly, "the motion activity specified by biomechanical principles of human motion which utilise motor features of movement and body structure to obtain the best sports result" (Bober *et al.* 1981, p502). Some authors (Cooper *et al.*, 1976, p10) avoid the term "technique" altogether and prefer to use the term "movement pattern". With respect to classical ballet, "technique" has been described as: "that manifestation of art from which a large part of the human personality has been excluded" (Mumford, 1952, p21; as cited in Hammond & Hammond, 1989, p16); "*what* the basic elements, positions, and movements are, and *how* they are to be performed" (Royal Academy of Dance, 1997, p5); "the correct execution of the steps and exercises" (Paskeva, 2002, p2); "the way in which dancers use basic physical movements in class or performance" (Berardi, 2005, p77); and "the foundational principles and steps on which ballet steps are built" (Wikipedia, 2011). The sport-related definitions listed above provide a more specific and consistent meaning for "technique" than the ballet-related statements. Collectively, the sport-related definitions suggest that "technique" describes kinematic characteristics relating to the relative positions of body segments during the execution of a movement task, whereas the definitions of ballet technique are more varied and perhaps more vague, thus preventing a succinct and clear interpretation of their meaning. So, it seems that despite its wide use within the classical ballet community, the word "technique" does not have a clearly established meaning. Consequently, for the purposes of this project, the word will be defined and used according to the sports-related descriptions listed above, namely the "relative position and orientation of body segments". This definition therefore implies that technique can be characterised by kinematic variables that can be visually perceived.

Although, classical ballet has a very distinct movement style, the actual movements themselves are not necessarily unique to the art form. In 1760 Jean Georges Noverre (1727 – 1810), one of the great ballet masters of the 18th century, described the 'Seven Movements of Dance', in terms of the quality or type of step (Lee, 2002). These movements are defined as:

1. Bend (*Plié*)
2. Stretch (*Battement*)
3. Rise (*Relevé*)
4. Jump (*Sauté*)
5. Glide (*Glissé*)

6. Dart (*Elancé*)
7. Turn (*Tour*)

Noverre's classification system is still referred to by many dance practitioners today However, on consideration of each term it is clear that these types of movement are not at all unique to classical ballet. There are many skilled movement disciplines in which these actions are performed. It is hard to think of any martial arts or skilled sporting activities where participants are not required to "bend", "stretch", "turn", "rise", or "jump". It would be expected that the biomechanical principles that enable highly skilled or elite execution of these movements would be similar whether a dancer, a gymnast, or an athlete were performing the task. For example, in terms of the trajectory of the whole body, the biomechanical principles that enable a hurdler to achieve an optimum jump over a hurdle, are likely to be very similar to those that would enable a ballet dancer to perform a skilful *grande jeté* (split leap), *i.e.* principles relating to projectile motion. What is of interest in this study however, is the identification and measurement of what it is that distinguishes a balletic jump or a turn, from a jump or turn in another movement discipline? What is it that a person must do with their body in order to be performing classical ballet rather than any other movement form? Essentially, it is this defining characteristic of classical ballet "technique" that this study aims to investigate, and which will be narrowed down to a definition of "the way in which the limbs and body segments are oriented with respect to each other while performing the movement". This section of the literature review will focus on identifying, from a theoretical point of view, *how* the limbs and segments of the body must be oriented with respect to one another in order for a dancer to be executing "correct" classical ballet "technique". The first stage of this review will be to consider the history of classical ballet, and investigate how this history has shaped the development of classical ballet technique.

2.1.2 The History and Development of Classical Ballet Technique

Most accounts of the history of classical ballet have placed emphasis on the unique contributions made by particular individuals and groups as they responded to the social and political forces of the time. Much attention has been paid to influential personalities and their creation and/or performance of memorable dance pieces. Dance historians have highlighted developments and changes in many of the artistic characteristics of classical ballet, including costumes, music, scenery and style, but few it appears have focused purely on the evolution and development of the technique itself. If one looks more narrowly at just the development of ballet technique, one finds a discernable, logical and rational order in the evolution of the technique over the past four centuries.

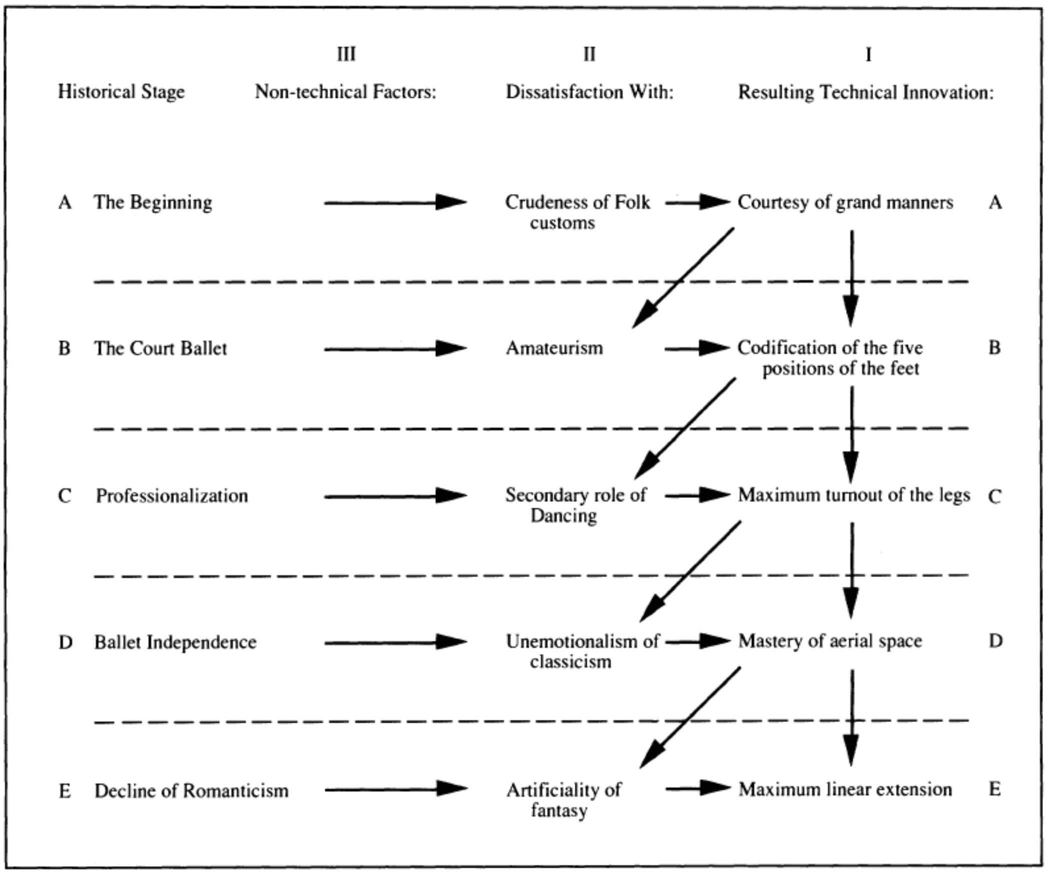


Figure 2.1 *Influences of selected changes in classical ballet (from Hammond & Hammond, 1989, p21)*

Classical ballet technique has developed in a series of stages. The important technical innovations introduced and absorbed into the ballet tradition during each stage have been described as being borne out of particular dissatisfactions with the existing conditions (Hammond and Hammond, 1989). These stages may be related to the periods ordinarily referred to when discussing the history of the arts (*e.g.* Middle Ages, Renaissance, Baroque, Romantic, etc.), however they are not necessarily the same. For this reason, a history of classical ballet focusing purely on its technical development may produce an account different from its stylistic history. Recounting the history of classical ballet technique in this manner, Hammond and Hammond (1989) have identified five stages in which major technical innovations emerged that are still evident in today's ballet technique. These stages can be labelled as the development of:

1. Courtesy of grand manners
2. Codification of the five positions of the feet
3. Maximum turnout of the legs
4. Mastery of aerial space
5. Maximum linear extension

This section of the literature review will discuss the history of the development of classical ballet technique in terms of the five stages presented by Hammond and Hammond (1979). Although the history of ballet technique will be discussed in relation to these five stages, other references will also be used to piece together the history of the technique.

2.1.2.1 <u>The Origins of Ballet: The Emergence of Grand Manners</u>

The early ancestors of classical ballet include various medieval folk practices such as religious processionals, pagan rituals and village dances (Hammond and Hammond, 1979). Before the eleventh century, the lives lead by the medieval nobility did not consist of delicacies or refinements that were vastly different from those of the common people (Lee, 2002). However, at the end of the eleventh century, European cultural centres began to develop in areas extending from the South of France to Northern Italy and Spain. During this time, refinement in all things became the objective of medieval court life. To this end they brought outsiders into their courts to instruct them in etiquette, comportment, music, dancing and poetry. The 'troubadours' who they employed for this task were learned poets, songwriters, composers and performers with aristocratic family background who had travelled widely, absorbing all kinds of information, including much of the classical learning from scholars of the Eastern Roman Empire. The troubadours' court dances stressed elegance of posture and precision of execution. The early conventional court dance style of the time thus became one of contrived elegance, with the dancers often appearing devoid of most of their spontaneous emotion (Lee, 1983).

The troubadours were credited with setting down rigid rules for their dance compositions and served as educators for close to two centuries during the late Middle Ages, spreading the presence and instruction of dance amongst the nobility of Western Europe.

By the 1400s instruction in social dancing was the standard for training gentlemen and women in their social behaviours. All members of the nobility were required to learn dancing and social etiquette so that they could conduct their lives with an appropriate manner of grace. By this time the roles of the troubadour had transformed into the singular profession of the 'dance master' with many achieving high rank as companions of princes. With the dance master came dance theory (Bland, 1976). Three prominent Italian dance masters from the 15^{th} century - Domenico da Piacenza, (ca. 1400 - ca. 1475), Antonio Cornazano (ca. 1431 - ca. 1515), and Guglielmo Ebreo (ca. 1440 - ca. 1484) – formed a basis of dance theory. Domenico's 1460 treatise *De Arte saltandi et choreas ducendi (On the art of dancing and conducting dances)* established that there was a body of independent ideas and codified dance steps that could be used in various sequences and contexts, and in this sense Domenico fostered the development of choreography (Lee 2002). Antonio Cornazano, a student of Domenico, commented extensively on the execution and relative merits of the steps created by Domenico in a 1465 manuscript entitled *Libra dell'arte del danzar (Book of the Art of Dancing,* yet another of Domenico's apprentices, Guglielmo Ebreo, wrote a treatise on dance, *De Practica seu arte tripudii (On the Practice or Art of Dancing) (1463),* that proved to be the earliest significant contribution to Western theatrical dance (Bland, 1976). Ebreo expanded on the ideas published by Domenico and wrote about dance in a way that made a clear distinction between folk dance and artistic dance with a required manner and aesthetic (Kassing, 2007). Widely read by dancing masters of the time, Ebreo's treatise called for the strict applications of rules in the execution of dance, and instructed its readers in the necessary qualifications for dancing that must be rooted in refined deportment. The dancing masters' concepts of the carriage, posture, and movements necessary for creating court dances for high society were further reinforced in a 1528 commentary on etiquette and social mores written by Count Baldassare Castigline (1478 – 1529) in *Libro del Cortegiano (The Courtier). The Courtier* had a profound influence on the evolution of European sensibilities and was a noted reference work for dance masters of the time (Lee, 2002).

Figure 2.2 *From Practica seu arte tripudii (1463). It was claimed that the dancers pictured capture the essence of the required skills and decorum for the dances of the time (from Bland 1976, p33).*

The dance styles and technique devised by the early dance masters formed the basis for much of the dance seen in the splendid Italian court entertainment during the Renaissance. Lavish productions took place in Italian palaces to celebrate weddings, birthdays or state visits. The dukes of the Italian city-states, who were greatly concerned with displaying their wealth and status to one another, competed with each other in giving these costly spectacles (Lee, 2002). Reasonably skilled members of the court nobility were selected to perform the exacting floor patterns and steps choreographed for these productions. The dancers were richly costumed and expected to closely adhere to the rules prescribed by the dance masters.

In 1547 Catherine de Medici (1519 – 1589), a member of the ruling family in Florence married the King of France, Henri II (1519 – 1559) (Anderson, 1992). She introduced into the French court the same kind of extravagant entertainment productions she had known in Italy. Known as *Ballet de Cour*, many of these productions were staged by Balthazar de Beaujoyeulx (1535 – 1587), a gifted musician who came from Italy to be

Catherine's chief musician (Anderson, 1992). Although the dance technique did not yet resemble ballet as we know it today, ballet historians consider one of Beaujoyeulx's entertainment productions, the *Ballet Comique de la Reine (The Dramatic Ballet of the Queen)*, to be the first 'ballet'. A description of the production was documented in a commemorative text, *Ballet Comique*. Several hundred copies of the printed *Ballet Comique* were presented to many European courts and wealthy families, inciting widespread imitation, thus cementing France's reputation of superiority in 'ballet'.

With their theoretical contributions, the dance masters of the fifteenth and sixteenth centuries helped lay down the foundations of a new style of dance that would continue to find much popularity in the courts of Renaissance Italy and France, eventually leading to the development of classical ballet as it is known today. Although greatly limited in technique by today's standards, the style did resemble the classical ballet style of today in that it was heavily based on the exhibition of a noble demeanor, displaying much elegance and grace (Homans, 2010). Dancers were required to move with dignity and danced according to rules carefully laid down by the dance masters of the time. "Careless manners, awkward stance, and imprecise movements were not tolerated. Fundamental to all was elegant posture – straight spine, lifted chest, relaxed shoulders, long neck, erect head, hands and arms held without tension" (Hammond & Hammond, 1979, p594). Such posture was the trademark of ballet at its beginnings, and remains so without exception in the ballet classrooms and theatres of today.

2.1.2.2 <u>The Court Ballet and the Five Positions of the Feet</u>

The production of lavish ballets continued in the French courts throughout the sixteenth and seventeenth centuries. The pinnacle of French court ballet coincided with the lengthy reign of King Louis XIV (1643 – 1715) (Anderson, 1992). Louis' father, Louis XIII (1601 – 1643), had been a fine dancer, thereby instilling Louis XIV with a love of dance from an early age. By participating in many court ballets Louis XIV gave dance respectability and encouraged others to work at perfecting the art (Lee, 1983). Although most dancers in the French court ballets were from aristocratic families, it gradually became more common to select dancers of less noble class who displayed greater skill. Louis XIV had great influence in the conversion of dance from amateur court entertainment to a professional occupation. In 1661 he performed the first formal act to establish ballet as a professional theatrical art by establishing the *Academie Royale de Danse (The Royal Academy of the Dance),* a professional organization to train dancers to perform for him and his court (Lee, 1983).

The *Academie Royale de Danse*, consisted of 13 ballet masters who he charged with the task of “re-establishing the art in its perfection”. The French academy served to “establish ballet technique and set artistic standards” (Hammond and Hammond, 1979, p595), and later came to be known as the Paris Opera Ballet. It was the king's ballet master Pierre Beauchamp (1631 – 1705) who began to work out exactly how each step should be performed and is credited with establishing the important principle that the feet must move to and from the five fundamental positions of the feet. He also described how to dance simple steps such as *chasse, glissade* and *pas de bourree* with turned out legs, as is still done today (Lee, 1983). From 1670 to 1687 Beauchamp, in collaboration with the talented composer Jean-Baptiste Lully (1632 – 1687), created dance works of extreme elegance. However it was not until 1681 that any females performed in the ballets created by the *Royal Academy*. This was supposedly a strength issue, as females were considered to be incapable of carrying the enormous headdresses, full heavy skirts and weighty corsets that constituted the costumes of the time. Female dancers performed professionally for the first time in 1681 in *Le Triomphe de l’Amour* (Nordera, 2007).

Figure 2.3 *Faune from Lully’s Le Triomphe de l’Amour (from Nordera, 2007, p26)*

The most important writing on ballet technique to emerge from the first years of professional dance was published in 1701 by the dancing master, Roaul Feuillet (c1653–c1709), who had previously served in Beauchamp's school (Anderson, 1992). Feuillet's book, *Chorégraphie ou l'art de decire la danse par caractéres, figures et signes démonstratifs (Choreography or the Art of Recording the Dance through Types, Figures and Demonstrative signs*), was essentially a technical manual. As written information, Feuillet's work served to stabilise the French ballet terminology and codify existing ballet steps (Lee, 1983). It systematically arranged existing steps and reiterated the five positions of the feet, including the distinction between the five "true" positions (feet turned outward) and the five "false" positions (feet turned inward).

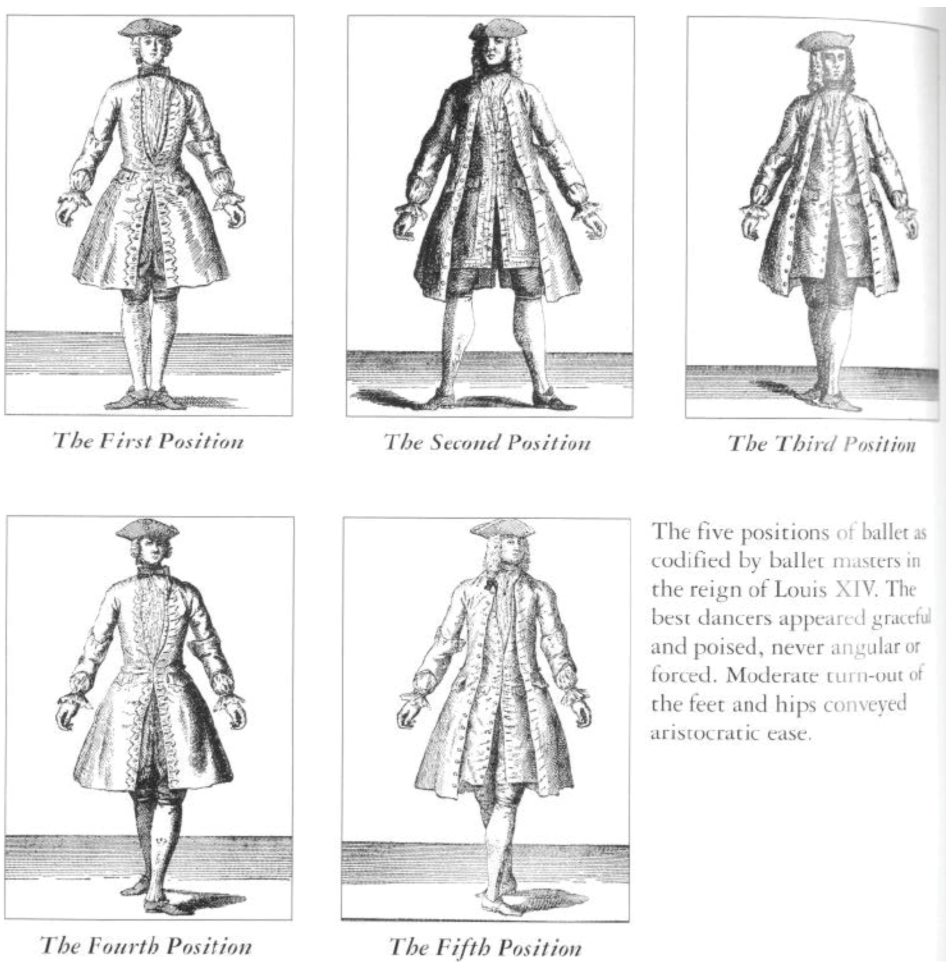
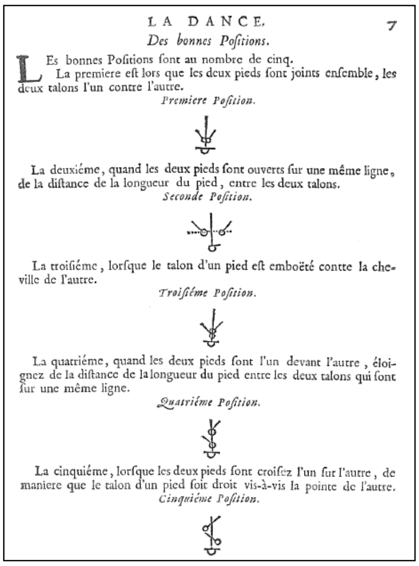


Figure 2.4 *The five positions of the feet (from Homans, 2010, p136).*



LA DANCE. 7

Des bonnes Poſitions.

LEs bonnes Poſitions ſont au nombre de cinq.

La premiere eſt lors que les deux pieds ſont joints enſemble, les deux talons l'un contre l'autre.

Premiere Poſition.

La deuxiéme, quand les deux pieds ſont ouverts ſur une même ligne, de la diſtance de la longueur du pied, entre les deux talons.

Seconde Poſition.

La troiſiéme, lorſque le talon d'un pied eſt emboëté contte la cheville de l'autre.

Troiſiéme Poſition.

La quatriéme, quand les deux pieds ſont l'un devant l'autre, éloignez de la diſtance de la longueur du pied entre les deux talons qui ſont ſur une même ligne.

Quatriéme Poſition.

La cinquiéme, lorſque les deux pieds ſont croiſez l'un ſur l'autre, de maniere que le talon d'un pied ſoit droit vis-à-vis la pointe de l'autre.

Cinquiéme Poſition.

Figure 2.5 *The five positions of the feet, as depicted by Feuillet in his Chorégraphie in 1700 (from Hammond, 2007, p67).*

Feuillet's manual was widely disseminated, being translated and published in 1706 by the English dancer John Weaver (1673 – 1760), under the title *Orchesography (Art of Dancing)*. Eleven years later in 1717, Gottfried Taubert (1679 – 1746) translated Feuillet's system into German under the title *Rechtschaffener Tanzmeister (The Worthy Dance Master)*, thus further extending the French influence on European dance. In 1724 another English dance master, Kellom Tomlinson (c.1690 - c.1753), used the various English translations of Feuillet's publication as a reference for his own collection of dances in the *Art of Dancing Explained by Reading and Figures* (Hammond, 2007).

Another important shift that took place during the reign of Louis XIV that influenced the development of ballet technique was the relocation of dance performances from the ballroom floor to a raised platform at one end of the room, that eventually became the proscenium stage (Hammond and Hammond, 1979). With ballets now being viewed by the audience from only one perspective rather than from all sides, the group processions and geometric floor patterns characteristic of the earlier court ballets gave way to greater emphasis on the movement of individual performers. Dance became more space oriented (Kraus *et al.,* 1997), providing new challenges for the choreographers as it was necessary for the dancer to be able to move skilfully and elegantly sideways so as not to turn away from their audience. The shift to the proscenium stage, and the consequent need for the dancers to move sideways, emphasized the usefulness and importance of the turned out position of the legs. The significance of the correct use of the five turned out positions of feet thus became entrenched into the classical ballet tradition.

2.1.2.3 Professionalisation and Maximum Turnout of the Legs

Professional ballet persisted as a major form of French artistic expression for decades after its introduction by Lully and Beuchamp. By the middle of the 18th century ballet was flourishing as a profession and all large French cities had ballet companies modelled after Paris (Lee, 2002). *The Royal Academy*, founded to preserve the dance as a uniquely French art, held the exclusive privilege of authorising all dance productions in state owned theatres. As a consequence, it was able to enforce its own traditions and conventions of *opera-ballet* in all the most important French theatres (Anderson, 1992). The tenets of its schooling and its art were guarded by law, and as a result its choreographers and teachers looked only to the formulas of past successes for ideas for their productions. Despite its growth in popularity, up until the mid-18th century many restrictions had been placed on the development of the art of ballet. Skilled dancers were weighed down by heavy and elaborate costumes, making free-flowing movements, jumps and lifts extremely difficult (Lee, 2002). By 1760, ballet masters began to question the restrictions placed on their art, which they saw as emanating from the days when ballet was part of the rigid protocols of the court. The complaint of the 18th century ballet masters was that ballet was not "artistic" enough (Hammond and Hammond, 1979). The greatest of these ballet masters was the French choreographer Jean Georges Noverre (1727 - 1810). In his *Letters on Dancing and Ballets* (1760), Noverre was the first to propose ideas that became central to the further development of ballet as a serious art form. Noverre believed that ballet should be a means of expressing a dramatic idea through the perfect combination of dancing, drama and character. Noverre claimed that the dancers "should be able to illustrate and express the plot, characters and emotions of a story using only their bodies and faces" (Noverre, 1760 - as cited in Lee, 2002, p111). Speech and singing were therefore discarded, as were restrictive wigs, masks and cumbersome costumes

> "…. away with those lifeless masks……take off those enormous wigs….discard the use of those stiff and cumbersome hoops…..Renounce that slavish routine which keeps your

> art in its infancy….let us gracefully set aside the narrow laws of a schools to follow the impressions of nature” (Noverre, 1760 - as cited in Anderson, 1992, p72).

Noverre was the first ballet master to succinctly classify the types of movements performed within the ballet repertoire. As stated previously, Noverre identified ‘Seven Movements of Dance’ and described them to be;

1. Bend (*Plié*)
2. Stretch (*Battement*)
3. Rise (*Relevé*)
4. Jump (*Sauté*)
5. Glide (*Glissé*)
6. Dart (*Elancé*)
7. Turn (*Tour*)

Noverre shared his ideas with many students, dancers, and choreographers of the time, and developed the *ballet d’action,* the earliest form of dramatic ballet that told the story completely through movement (Anderson, 1992). In doing so he turned the attention of ballet masters towards the development of the individual dancer as an artist, thus causing a major advancement in the dancer’s technique. For women, who were now receiving increased recognition as credible dancers, the removal of the long-hooped skirts allowed a freedom of leg movement not previously seen. High-heeled shoes were replaced with heelless ballet slippers, which encouraged more steps of elevation (Hammond and Hammond, 1979). The combination of the five positions of the feet and this new found freedom meant that dancers were now attempting faster beats, more controlled *pirouettes*, and higher leg extensions. They subsequently discovered that even more outward rotation of the legs better facilitated the execution of these movements. According to Noverre, “In order to dance well, nothing is so important as the turning outwards of the thigh” (Noverre, 1760 – as cited in Anderson, 1992, p72).

At the beginning of the 18th century, the correct use of the five “true” positions of the feet required each foot to be rotated outwards by about 45º, that is, with the feet positioned at right angles to each other. However, this degree of rotation was later deemed to be insufficient for the lighter clad professional dancers of the late 18th century (Hammond and Hammond, 1979), and by 1800 was increased to 90°, which became the new required technical standard, a permanent feature of classical ballet technique that is still strived for today.

Thus, by the end of the 18th century the fundamental principles of the classical ballet technique had expanded to include: the exhibition of grand manners and elegance; correct use of the five positions of the feet with 90º turnout. By this time many great public performing institutions had been established, along with their affiliated professional ballet schools which became the place for specialised ballet instruction (Lee, 2002). The Paris Opera Theatre, established in 1669, had paved the way for the development of London's Haymarket (1705), and later Covent Garden (1732); the Royal Danish Opera (1726), the Vienna Burgtheater (1748), the Royal Swedish Opera (1773); La Scala in Milan (1778), and the Bolshoi in Moscow (1776).

2.1.2.4 Ballet Independence and Mastery of Aerial Space

By 1800 ballet was no longer a mere distraction within opera or drama but had gained a measure of artistic independence and could hold the stage alone (Hammond and Hammond, 1979). However, the increased focus on the technical qualities of classical ballet during the 18th century soon started to diminish, and a shift in attention towards the emotional content of the productions started to occur. The Romantic movement of early 19th century Western Europe brought about a change in the direction of the art form, with a new focus on the values of human emotion and individualism, in contrast to the rational and logical ideals of the previous era (Lee, 2002). The significant feature of the Romantic ballets therefore was their highly emotional content. A new generation of European artists created dance productions that expressed immense feeling and depicted a strong desire to transcend the human condition into exotic places inhabited by supernatural creatures. The creative high point of the Romantic ballet occurred between 1830 and 1845. The two memorable ballets of the period, *La Sylphide* (1832) and *Giselle* (1841), portrayed the realism of rustic village settings against the ethereal world of fairy creatures known as *Sylphs* or *Wilis*. The contrasting themes of the subject matter greatly enriched the choreographic content and diversity within the Romantic ballets, thereby enhancing the dancers' technical requirements. The unreal or supernatural sections of the ballets called for a greater development of the aerial aspects of the technique. That is, in order to successfully interpret these ethereal or otherworldly characteristics, the dancers had to display a superior quality of lightness, or *ballon* (Lee, 1983). For this reason, jumping steps were refined and perfected for the meaning that they could bring to the portrayal of mystical beings. This notion was suitably captured by the words of famed Italian ballet teacher and theorist, Carlo Blasis (1795 – 1878):

> "Be as light as possible………I would like to see you bound with a suppleness and agility which gives me the impression you are barely touching the ground and at any moment may take flight" (Blasis, 1820, p46).

The innovation that contributed most significantly to the creation of the ethereal mood of the Romantic ballets was the inclusion of *pointe* work. Dancing *en pointe,* the common term used to refer to dancing on the tips of the toes, helped dancers achieve the illusion of defying gravity. The Romantic ballerina Marie Taglioni (1804 – 1884) is credited with introducing the modern *pointe* technique and was seen to dance the full length *La Sylphide en pointe* (Kant, 2007). *Pointe* work became mandatory for all female dancers during the Romantic period as it provided the ultimate illusion of weightlessness that characterised the creatures of fantasy depicted in the ballets of the era. The first *pointe* shoes were delicate, heel-less, close-fitting, satin slippers which were part of the fashion of the times (Kant, 2007). They were reinforced around the leather sole and the toes with extra stitching and featured long ribbons that wound around the ankle to give extra support. Starched muslin, felt, or cardboard wrapped around the foot also added to the shoe's strength (Lee, 2002). Not until 1880 were the first commercial blocked *pointe* shoes introduced, so the female ballet dancer of the Romantic era had to develop her foot and ankle strength without artificial aids (Lee, 1983).

The thematic material of the Romantic ballets enabled the female dancer to reign supreme during this period. The ballerina's increasing use of her *pointes* made her balance more precarious, requiring highly attentive partnering from her male partner. This contributed to the development of greater complexity in the *pas de deux* (dance for two) between the male and female dancers that served not only to display great tenderness and emotion, but also the practical need to assist the female dancer's balance *en pointe*. Although there were some very good male dancers of the time, most were used only to assist the ballerina and carry her around the stage. Consequently, by the mid 19th century comparatively few male dancers were enrolled in the professional ballet schools. For the first time in the history of dance, the female presence superseded that of the male (Lee, 2002). This emphasis on the female ballet dancer allowed the development of the ballerinas' technique. With more attention paid to their technique, women became celebrated as performers.

With the rise in importance of the individual female dancer, ballet teachers and masters set about formulating the rapid growth of pedagogical innovations in classroom instruction. It was the inspiration of a number of prominent ballet masters, in particular Blasis, Taglioni, Jules Perrot (1810 – 1892) and Arthur Saint Leon (1821 – 1870), that provided the female dancers with the technical and choreographic challenges on which their individual fame rested (Lee, 1983).

Although more has been published about Romantic ballet in Paris and London than in other European cities, a great deal of activity also took place outside these two centres. In Italy, due to the distinguished reputation of the Italian ballet master, Carlo Blasis (1795 – 1878), Milan enjoyed a special prominence in the world of 19th century ballet. In the early part of the century, Blasis published two manuscripts on the analysis of ballet technique. His 1820 work, *Traité élémentaire, théorique, et pratique de l'art de la danse ("Elementary Treaty on the Art of the Dance, theory and practice"),* was followed by the 1828 manuscript, *The Code of Terpsichore (The Art of Dancing),* which became the standard for European ballet instruction and guided entire generations of dancers (Lee, 2002). Blasis' teaching methods perfected the aerial and floating qualities required for the Romantic ballets. He methodically applied the physical laws of equilibrium to the human body, an approach that gave rise to the current ideas of balance, placement, alignment and centredness in classical ballet (Lee, 2002). His geometrical interpretation of the body with respect to classical ballet positions developed in his students a sense of the same body placement and alignment that the dancers of today strive to achieve.

> "Strive to acquire perfect bodily equilibrium and to achieve this end never deviate from the perpendicular which should extend from the centre of the collar bone down between the ankles of both feet." (Blasis, 1820, p34).

> "If a dancer is to remain balanced upon one leg, or for that matter well poised upon both, he must, besides disposing himself gracefully, establish the correct counterpoise of all other parts of the body". (Blasis, 1820, p34).

> "The body should be held erect in a perpendicular line with the legs, except in certain positions, notable arabesque, where one is obliged to lean backward or forward. The position notwithstanding, the body must always rest firmly poised upon the hips. Throw out your chest and hold your waist in, keep your knees springy and brace your back" (Blasis, 1830). (Blasis, 1820, p25).

Blasis manuscripts were the first comprehensive books on ballet technique, as we understand it today, to appear in print. In 1837 Blasis was appointed as the director of the *Imperial Regia Accademiadi Danze (The Imperial Academy of Ballet and Pantomime)* in Milan. The ballerinas trained there were renowned for their exceptional technique, and were soon in demand everywhere in Europe. The structure of the today's ballet class stems from Blasis' three-part class. The *barre* exercises progressively train the body to form the prescribed classical shapes. The exercises are then repeated in the centre of the room without the support of the *barre*. In the final phase of the class, all the elements of the *barre* are transformed into dynamic dancing movements with the addition of jumping and turning movements (Lee, 2002). He reinforced his theories with illustrations depicting the balanced poses and well-balanced torsos required for the execution of superior technique. He devised long combinations of steps known as e*nchainements* to develop lung capacity, leg strength and stability so that the dancers could cope with the new complexities that choreographers were inventing (Lee, 2002). Thus, from the early to mid 1800s, the specific theoretical principles of classical ballet technique were refined and consolidated as the structure of the modern day ballet class developed and countless ballets replicating *La Sylphide*, and *Giselle* were produced. This era therefore saw classical ballet achieve its modern identity as it acquired many of the characteristics that are associated with it today: the *pointe* technique; the tutu; and the desire to create the illusion of weightlessness and effortlessness. Significantly, most of these characteristics apply solely to the female dancer, as stated previously, in the course of the 19th century the male dancer suffered a considerable loss of prestige. Thus, by the mid 1800s classical ballet had developed into an art form that was clearly based on the features of grand manners, codified foot positions, 90º turnout, and now the addition of elevation and *pointe* work.

2.1.2.5 Decline of Romanticism and Maximum Linear Extension

As the mid-19th century approached, the Romantic ballet began to lose its impact and by 1850 the glory of the Romantic ballet's golden age had all but disappeared. The last quarter of the century saw the abandonment of the Romantic period's artistry and expressiveness, in favour of a more superficial concentration on technical virtuosity and visual spectacle. The great European choreographers of the Romantic era had passed away, and no new talents had risen to take their place. Ballet seemed to have lost its creative momentum, and the public had ceased to regard it as a serious art form. In France, where ballet was protected and housed by the Paris Opera, a lack of significant talent and public interest in the art contributed to its decline. In Italy, art patrons were beginning to prefer operas to the overly repetitious ballets of the time. Thus, towards the close of the 19th century, ballet in Western Europe was no longer a mainstream art, as it had been in the 1830s and 1840s, and appeared to be about to die of exhaustion.

While the Western European public were losing interest in ballet during, the art form was steadily developing in Russia under the influence of the Russian Empire. Since 1738, ballet in Russia had received Imperial protection and support because it initially existed as court entertainment. During the 19th century the Maryinsky Theatre in St. Petersburg (known as the Kirov Theatre during the Soviet years) and the Bolshoi in Moscow were state owned and controlled, with the directors of these companies being personally appointed by the tsar (Anderson, 1992). Although there were some excellent Russian dancers in St. Petersburg throughout the Romantic period, Western European dancers and choreographers had been increasingly travelling to Russia, and so contributed to the development of Russia's own successful Romantic age. A new era in Russian ballet began when a French dancer, Marius Petipa (1818 – 1910), arrived in St. Petersburg in 1847. While the popularity of ballet was declining in the West, Petipa was initiating a new force in the development of ballet which saw the synthesis of the most significant technical advancements from both the Russian and European Romantic era (Lee, 1983). With the presence and eventual leadership of Petipa, the Maryinsky Theatre in St. Petersburg became a vital dance centre. For nearly forty of the sixty years he was in Russia, Petipa's concepts of training, choreography and production dominated the dance at the Imperial School of Ballet and the Maryinsky Theatre, and to a lesser extent, that of the Bolshoi Theatre in Moscow.

Petipa's contribution to the ballet repertoire was significant. Among his masterpieces that are still performed today, are *Don Quixote, 1869; La Bayadere, 1877; Sleeping Beauty, 1890; The Nutcracker, 1892; Swan Lake, 1895;* and *Raymonda, 1898.* However, by century's end, the Russian moment in ballet was over, and Petipa's generation passed abruptly from the scene. Petipa's legacy however was enormous. Under his leadership, the entire axis of classical ballet had shifted. For two centuries, the art form had been quintessentially French, but from this point on, classical ballet would be seen as Russian (Homans, 2010). It is two great Russians, Serge Diaghilev (1872 – 1929) and Mikhail Fokine (1880 – 1942), who are largely held responsible for the reform and redevelopment of ballet that soon took place within Europe in the early 20th century.

Diaghilev was born a member of the Russian nobility. He was not a dancer, choreographer or composer, in fact he studied law, but later became interested in ballet and opera, and was given a supervisory post at the Maryinsky Theatre. Because of his independent and forthright character, he found it difficult to work there and resigned after only a brief period (Kirstein, 1987). He was ambitious and innovative and went on to produce art exhibitions in St. Petersburg and Paris, and in 1908 he became a theatrical impresario. It was in this role that he made his significant contribution to dance. In 1909 he assembled a group of leading Russian dancers from the Imperial Ballet to form a new company, the Ballet Russes, and arranged to present a season of dance in Paris. The selected dancers, all of whom had graduated from the Imperial Theatre School at or near the turn of the century, were part of a new generation of Russian dancers that came in the wake of Petipa. The list of dancers included historically significant names such Mikhail Fokine, Anna Pavlova (1881 – 1931), Tamara Karsavina (1885 – 1978) and Vaslav Nijinsky (1889 – 1950). The ballerinas of this generation were physically distinctive from their voluptuous and sturdy predecessors. They were long and lithe, with smooth lines, and evenly developed muscles and a soft sensuality (Homans, 2010). This was primarily due to the training they had received at the Imperial Theatre School under the guidance of the Italian ballet master Enrico Cecchetti (1850 – 1928). Cecchetti, who arrived in St. Petersburg in 1887, belonged to the old Italian school so his teaching methods were directly rooted in the pedagogy of Carlo Blasis. He emphasised repetition and tricks, and designed long gruelling *enchainements* to build strength and endurance. In doing so, Cecchetti gave his students the tools to redefine classical technique. Rather than dwelling on the types of steps and bravura stunts, the new generation of dancers used their technical abilities to sculpt their bodies and develop soft and flowing movements for which extreme flexibility was highly emphasised. Anna Pavlova, the prototype of the new Russian ballerina of this time, was described as being "thin with highly arched feet, gangly arms and a long straight neck….the line of her leg was slender and tapering…she looked wispy and evanescent without a hint of heavy strength or bravura" (Homans, 2010, p292). This description is typical of the vast majority of professional female ballet dancers working today.

In the early 1900s Diaghilev formed a new ballet company, the Ballet Russes, for which he appointed Michel Fokine as the first choreographer. Fokine, an experienced choreographer, had previously worked from 1900 with the St. Petersburg company (Kraus *et al.*, 1997). Together, Diaghilev and Fokine, aimed to create a new and innovative repertoire. Fokine urged that technique should be the means to express character and emotion. He felt that a dancer's entire body, rather than separate mimed gestures, should express the story or concept at all times. The choreographic works of Fokine therefore matched well with the increased physical fluidity and suppleness that the new generation of graduating dancers of the Imperial Theatre School had developed. The result for ballet was a significant increase in the breadth of physical movement, especially in the range and mobility of the limbs - referred to by Hammond and Hammond (1979, p600) as "maximum linear extension". For example, the leg which, in the 19th century, was raised to a point parallel to the floor, was, in the 20th century, capable of being extended above the head, almost perpendicular to the floor. This extension was possible because it built upon its technical predecessors - a capacity for extreme turnout and the strength and lightness involved in mastering aerial space. That is, it was a movement style, or element of the technique, that would have been impossible for the ballet dancer of the 18th century (Hammond and Hammond, 1979).

Displaying new extremes of physicality and flexibility, Diaghilev's Ballet Russes, opened to great acclaim in Paris in 1909. Until this time, ballet in France had not regained the highly regarded status it held during the Romantic era. The arrival of the Ballet Russes was therefore received by Paris' audiences with extreme enthusiasm. The male dancers, among them Vaslav Nijinsky, were particularly admired because elite male dancers had almost disappeared in Paris. For his time, Fokine's choreographic ideas were revolutionary, and the French patrons were thoroughly excited by the brilliant Russian dancers' disregard for the rigid conventions of the past and their ability to dance in a way that used their entire body to portray emotion. This event marked the rebirth of ballet in the West. Following its hugely successful debut in Paris, the Ballet Russes toured throughout Europe to continued acclaim. Over a period of 20 years (1909 - 1929), without any permanent base, the company travelled to many European cities, and also to the Americas. Many new dancers were employed initially from Russia, but World War I and the Russian Revolution (1917) separated the company from its homeland during the company's middle years. Fresh new talent was therefore sought from the West, a time which saw English dancers Alicia Markarova, Antony Dolin and Marie Rambert, and Irish dancer Ninette de Valois join the ranks. In 1924, towards the end of the company's existence, Russian born George Balanchine (1904 - 1983) was recruited after defecting from Soviet Russia. Throughout the lifetime of the Ballet Russes company, Diaghilev employed a succession of choreographers to produce new and innovative works. In addition to the founding choreographer, Fokine (*Prince Igor, 1909; The Firebird, 1910*; *Petrouchka,1911*), other great names who choreographed for the Ballet Russes included Nijinsky (*The Afternoon of a Faun, 1912; The Rite of Spring, 1913*), Leonide Massine (1895 – 1979) (*Parade, 1919*), Bronislava Nijinska (1890 – 1942) (*Les Noces; 1924),* and in the company's final years, a still very young George Balanchine (*Apollo, 1928; The Prodigal Son, 1929*).

Upon Diaghilev's death in 1929, the Ballet Russes disbanded and the company's dancers and choreographers scattered around the globe to initiate major developments in ballet's worldwide growth. Fokine worked with many companies, including the future American Ballet Theatre. Massine contributed to the Ballet Russe de Monte Carlo, a company formed after Diaghilev's death. The Polish-born dancer Dame Marie Rambert (1888 – 1982) and the British dancer Dame Ninette de Valois (1898 – 2001), became the founders of British ballet. Rambert's students included the British choreographers Sir Frederick Ashton (1906 – 1988), Antony Tudor (1908 – 1987), and John Cranko (1927 – 1973). De Valois founded the company that became Britain's Royal Ballet, for which celebrated dancer Margot Fonteyn (1919 – 1991) danced from 1935 to 1979. Balanchine was invited by Lincoln Kirstein, a wealthy young American patron of the arts to work in the United

States, from where he went on to form the School of American Ballet and New York City Ballet. The Russian ballerina Anna Pavlova, who danced in the early seasons, formed her own company and toured internationally. One of Pavlova's dancers, Edouard Borovansky (1902 –1959) later settled with his wife in Australia where they established the Borovansky Ballet Company, which in 1962 formed the basis for The Australian Ballet Company. Before this migration of artists in the 20th century, ballet was only known to relatively small and elite groups (Lee, 2002), but within a few generations this group's knowledge and dedication to dance has been disseminated across multiple continents to millions of people.

Thus, by the early 20th century the fundamental technical requirements of classical ballet as we know it today had been established, and by the mid 20th century specific detail and knowledge about the technique had been disseminated around the world. It became expected that a professional ballet dancer would possess the technical attributes of grand manners, codified foot positions, 90º turnout, elevation and *pointe* work, and finally extreme flexibility displayed through maximum extension of the lower limbs. These defining qualities of classical ballet technique remain largely unchanged today.

2.1.2.6 Classical Ballet Today

While the defining fundamental technical characteristics of classical ballet technique have changed little since the early 20th century, the skill and complexity of movements that the dancers of today are able to execute has steadily increased throughout the 20th and 21st centuries. This has in large part been due to specific syllabi and training methods that have been developed throughout different regions of the world. The ballet syllabi most commonly used to train ballet dancers throughout the world today are the Royal Academy of Dance Syllabus; the Cecchetti Method, the Vaganova System, and Balanchine Method.

First established in the United Kingdom in 1920, The Royal Academy of Dance (RAD) is currently one of the world's largest dance education and training organisations. Today the RAD has a presence in 79 countries, with 36 offices and over 13,000 members worldwide (http://www.rad.org.uk). The RAD offers an internationally recognised portfolio of examinations and assessments for students of all ages and levels of ability. Classical ballet technique is taught using a systematic syllabus, for which commencing students may be as young as 6 years of age. The system consists of Graded (Grades 1-8) and Vocation levels of study.

Enrico Cecchetti, one of the world's outstanding teachers of ballet of the late 19^{th} and early 20^{th} centuries, established a system that passed on the tradition of ballet to future generations of dancers. This system, the Cecchetti method, was codified and recorded by Cyril Beaumont, Stanislas Idzikowski, Margaret Craske, and Derra de Moroda (Grant, 2008). The method has a definite program of strict routine and includes a table of principal daily exercises for each day of the week (Grant, 2008). The Cecchetti Society was formed in London in 1922 to perpetuate his method of teaching. In 1924, the society was incorporated in to the Imperial Society of Teachers of Dancing. Entrance to the Society is by examination and students must pass through a carefully graded system which has done much to raise standard of dancing throughout the British Empire.

During the 1920s, the Russian ballerina and teacher Agrippina Vaganova developed a planned instructional system which later became known internationally as the Vaganova System. Vaganova was personally responsible for revamping the pedagogical system that produced Russian dancers (Lee, 2002). A new period of dance pedagogy began with the publication of Vaganova's *Basic Principles of Classical Ballet (1934).* Her methods expanded the entire body of technical knowledge so comprehensively that it became the system on which Russian ballet training is based to this day (Grant, 2008). Vaganova's exacting demands of her graded syllabus meant that ballet teaching in Russia became entirely professional. Retiring dancers could no longer claim the right to teach without first completing a two year training course (Lee, 2002).

The Balanchine Method is a ballet technique and training system devised by the Russian dancer and choreographer George Balanchine and initially used at the School of American Ballet, the school of the New York City Ballet, and at many schools of Balanchine's disciples, such as Miama City Ballet, Ballet Chicago Studio Company and the Suzanne Farrell Ballet in Washington D.C. The overall illusion of the Balanchine Method is that dancers are utilising more space in less time: speed, height, length and a syncopated musicality are created (Schorer, 1999). Dancers must therefore be extremely fit and flexible.

Technical manuals for each of the aforementioned ballet training syllabi or systems, as well as other literature sources, will be referred to in the following section, which will focus on describing and succinctly defining the fundamental principles of classical ballet technique. In defining the fundamental principles of the technique, it is the similarities amongst the various training systems that will be focused on, rather than the unique characteristics of each system. The next section will outline the fundamental principles of classical ballet technique.

2.1.3 The Fundamental Principles of Classical Ballet Technique

The review of the history of classical ballet technique, shows that the technique we know today developed through a series of logical progressions and advancements: some due to social influences (*e.g.* grand manners); some grew out of physical necessity (*e.g.* turnout); and others from the stylistic inspiration of particular individuals or various phases of European artistic history (*e.g.* five positions of the feet; mastery of aerial space; maximum linear extension). It is clear that each stage directly contributes to identifying and defining a few key principles of the technique. For the purposes of this thesis, four key principles have been identified:

1) ‘Alignment’
2) ‘Placement’
3) ‘Turnout’
4) ‘Extension’

These fundamental principles of classical ballet technique will be clearly defined and described in the follow sections.

2.1.3.1 Alignment

‘Grand manners’, the first of the technical requirements that had been established by the beginning of the 20th century, specified deportment and carriage of the upper body. It outlined a desired aesthetic that remains current, namely extreme elegance and poise. Classical ballet dancers are expected to maintain this aesthetic while executing various movements with the lower limbs. For example, a professional ballet dancer is expected to be able to raise one leg to a very high level at the front, side or back of their body, while maintaining an upright vertical posture with their torso. This requirement is consistently identified in many dance literature sources, dating from as far back as the 1820 writings of Carlo Blasis through to the more contemporary writings of today's major ballet syllabi. The following quotations and figures support this requirement.

> "Strive to acquire perfect body equilibrium and to achieve this end never deviate from the perpendicular which should extend from the center of the collar bone down to between the ankles of both feet. The body should be held erect in a perpendicular line. A fine carriage is one of the principal merits in a dancer. The upper part of the body should always be displayed with elegance. While dancing, the body must remain quiet and absolutely steady. The dancer who jerks his body, raises his shoulders in reflex action to his leg or bends his back to facilitate execution is a ridiculous sight. These mischievous dancers, whose sole contribution consists in fostering bad taste, should be banished from the theatre" (Blasis, 1820, p24-25 & p34).

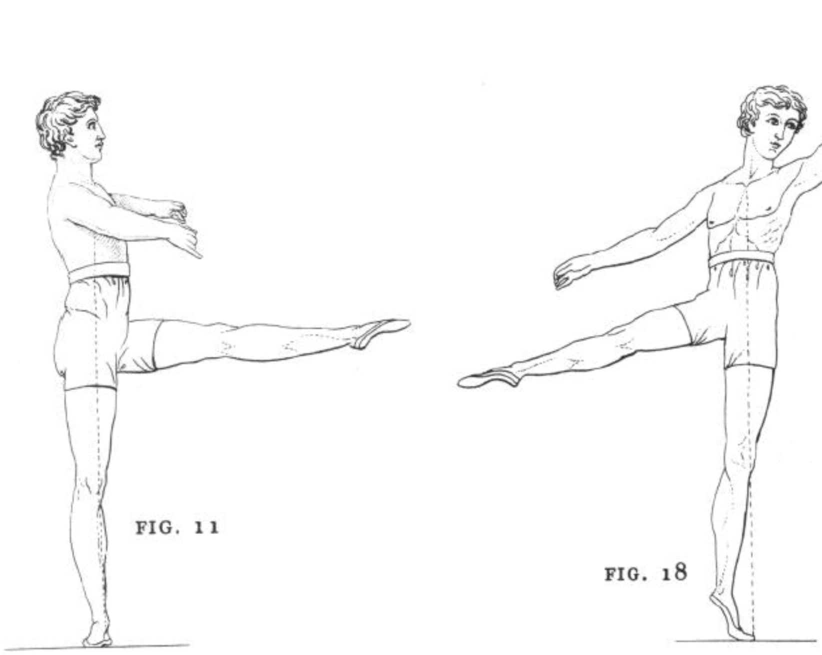
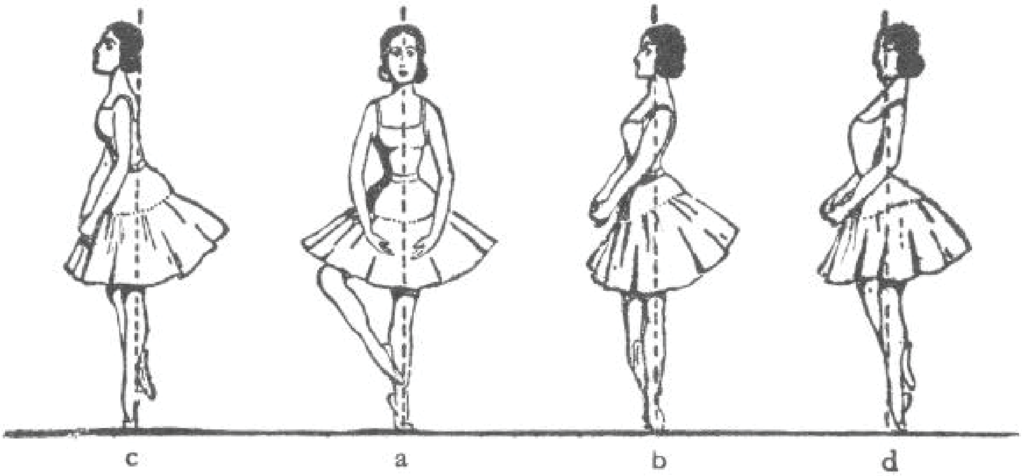


Figure 2.6 *Correct "perpendicular" alignment of the body (from Blasis, 1820, p18 & p26)*

> "Keep your body poised erect and perpendicular on your legs. In the execution of your steps, let the body be quiet, firm and free from jerkiness. A common fault of pupils is throwing out their waist at the same time as throwing out their chest, (ii) throwing out their posterior when required to keep in their waist" (Beaumont and Idzikowski, 1932, p30).

"To master stability in the dance, to gain aplomb, is a matter of primary importance to every dancer. A body which does not stand straight on the foot, but inclines towards the *barre*, will never gain aplomb and balance. The stem of aplomb is the spine" (Vaganova, 1953, p24-25).



8. Position of the body: a, b—correct; c, d—incorrect

Figure 2.7 *Correct and incorrect alignment of the body for classical ballet technique (from Vaganova, 1953, p25).*

"A 'ramrod' spine is needed. A firm grip in the muscles of the spine is essential. If the spine and buttocks are relaxed, the trunk will incline forward and the 'tail' will stick out." (Karsavina, 1962, p10).

"Stability is one of the basic elements of classical dance. The basis of stability lies in the preservation of the vertical axis, which passes through the middle of the head and body to the ball of the supporting foot when one is standing on *demi-pointe* and in front of the heels when one is standing on the whole foot. The body is in a vertical and pulled-up position in all exercises." (Kostrovitskaya and Pisarev, 1978, p62).

"The tail (coccyx) and pelvis must be pulled downwards and the spine upwards from the waist. The three natural curves of the spine are thereby straightened. The head must be held erect so that the crown is directly over the insteps of the feet." (Lawson, 1979, p13).

"The term alignment is used to denote the precise vertical positioning of all the sections of the torso, in relation to all parts of the legs as it is seen in profile. Good posture can be thought of as beginning with the spine stretching upwards and downwards. The feeling in the thoracic area is one of lifting upward in an upward and vertical pull" (Lee, 1983, p207).

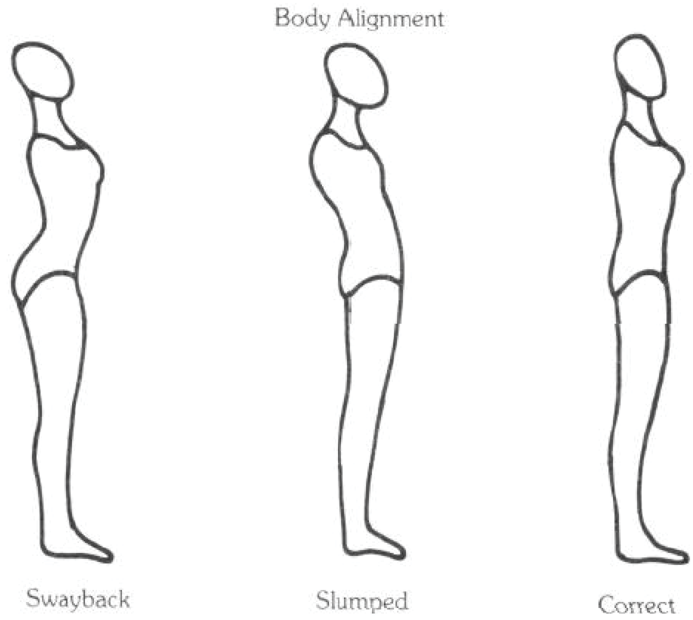


Figure 2.8 *Correct and incorrect body alignment (from Lee 1983, p207)*

"The basic stance of classical ballet elongates the spine so that the natural curves are diminished, though by no means eliminated. The key to good posture is the correct alignment of the spine. The bony masses of the skeleton – head, rib cage, and pelvis are stacked vertically, like building blocks, over their base, the legs and feet. This balanced position, with the shoulder girdle hanging easily on top of the rib cage, causes the line of gravity – the imaginary line that exactly bisects the weight of the body – tall fall through the centre of the structure. All parts, on either side of the line, balance each other. Viewed from the front or the back, the line bisects the body into two symmetrical halves." (Grieg, 1994, p17).

"Central to the basic stance is the concept of aplomb. Mme Vaganova used the term to refer to vertical stability and alignment. Seen from the side, the line of the dancer's body (from head to toe) will appear to incline almost imperceptibly forward, so that the shoulders are in vertical alignment over the front of the pelvis, slightly favouring the balls of the feet." (White, 1996, p90).

"The spine forms the central axis of the body, and is composed of two forward and backward curves. In the dancer these are held in a lengthened position by the abdominal muscles at the front and the extensor muscles at the back. The sides of the waist are kept equally lengthened and stabilised by support from the oblique abdominal muscles. Whether the dancer is performing *adage* with high extension or *allegro*, the length of the back and sides is retained as far as possible. It is the training, strengthening, and strong control of the spine that advances classical ballet technique" (Royal Academy of Dance, 1997, p8).

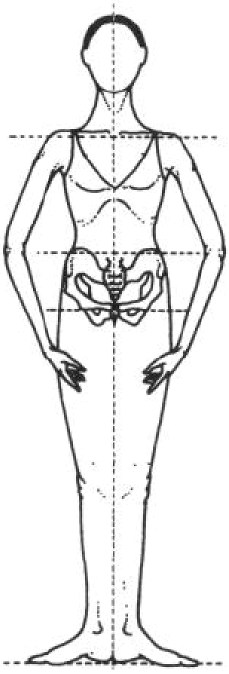


Figure 2.9 *The correct lengthened position of the spine (from The Royal Academy of Dance 1997, p8).*

"'Stand upright like you swallowed a yard stick' Mr Balanchine wanted us to stand straight, with the shoulder square to the *barre*, held down and open. The chest was proudly lifted." (Schorer, 1999, p52).

"In order to achieve an untrammelled classical line, attention must be given to the verticality of the body, produced by alignment of the spine. The classically straight back is achieved by minimising the curvatures of the thoracic and lower dorsal areas. The practice of alignment starts by standing erect keeping an elongated spine. This position lengthens the spine, allowing each section of the torso to occupy the space it needs without impinging on another part. The result of this alignment is a posture that gives dancers a characteristic super-uprightness. It is not to be confused with stiffness, in fact, it is its exact opposite; rather this position can be described as a pliable verticality. Maintaining verticality with ease means that the line of gravity is shifted to the supporting side; all the muscles of the torso and pelvis are engaged in that positioning." (Paskeva, 2002, p11 & Paskeva, 2005, p39).

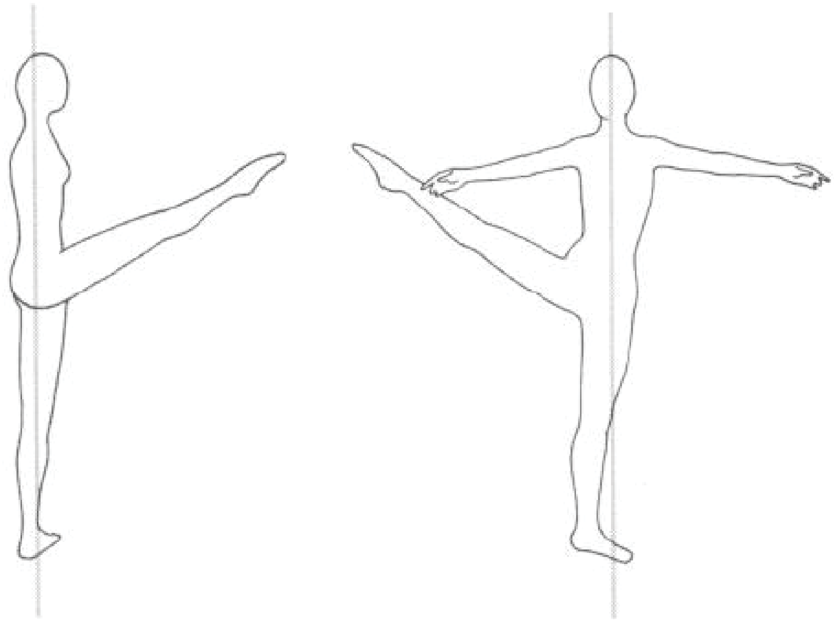


Figure 2.10 *In leg extension to the front or side, the body is expected to remain close to the vertical (from Paskeva, 2005, p43).*

> "Straight spine, relaxed shoulders and neck, arms firmly held, and neck erect is the first requisite for all exercises. The body is poised and ready to move". (Walczak and Kai, 2008, p246).

Collectively, the previous quotations indicate the importance of maintaining an elongated vertical spine while executing all traditional classical ballet movements. For the purposes of this project, this principle of the classical ballet technique will be referred to as 'alignment' in all future sections of the thesis. The principle of 'alignment' will thus be succinctly defined as "maintaining verticality of the torso".

2.1.3.2 Placement

To achieve the desired elongated torso, the position of the pelvis cannot be ignored. The orientation of the pelvic segment contributes to the overall appearance and apparent length of the spinal column, and therefore plays a crucial role in the execution of correct classical ballet technique. An incorrectly positioned pelvis, with respect to the thorax, will influence the shape of the lumbar spine. Thus, in addition to the position of the thoracic segment, appropriate positioning of the pelvic segment also plays a role achieving an elongated appearance of the torso, and therefore "grand manners". Many authors on classical ballet technique have provided instruction on the correct position of the pelvis for classical ballet. It should be noted however that in discussing the pelvic placement for ballet, some authors refer to the 'hips' rather than pelvis. However, in relation to this usage of terminology most dance writers are typically referring to the anterior superior iliac spine (ASIS) of the pelvis, rather than the actual hip joint. The following quotations from various authors indicate how the pelvis ('hips') should be placed in classical ballet.

> "He who whilst dancing moves his body by jerks, bends or relaxes his loins to facilitate the execution of his *tems*, is unquestionably an object of ridicule, and the name of a *grotesque* would suit him much better than that of a dancer" (Blasis, 1828, p66).

> "Let the body be quiet, firm and free from jerkiness, a common fault is throwing out the posterior when required to keep in the waist" (Beaumont & Idzikoeski, 1932, p30).

> "When the leg is thrust out to the front, side or back, the upper part of the leg, the hip, should not be raised too high. It should be done so that the leg works independently, without involving the body in the movement." (Vaganova, 1953, p28).

> "The hips must be square to the position of the feet. The tendency, very frequent, of throwing out the hip of the working foot must be checked. The shoulders have to be, at this stage, in line with the hips" (Karsavina, 1962, p40).

> "The basic conditions for the mastery of stability are the correct distribution of the pulled-up body over both legs or over one, and level hips." (Kostrovitskaya, 1978, p63)

> "The pelvis must be balanced over the two legs and held firmly by the so-called 'muscular corset' with the hips level at all times. The dancer must be in correct placement with hips and shoulders level and lying parallel to each other, facing the same plane. In pure classical dance there should be no curving forwards, sideways or backwards below the waist" (Lawson, 1979, p13).

> "The term 'placement' in ballet refers to the precise horizontal positioning of the shoulder and pelvis area as viewed from the front or back planes of the body. That is, the horizontal lines of the shoulder joints and crests of the pelvis are parallel to each other and the floor when the body is supported by both legs. Correct placement in ballet technique hinges on two rules of thumb. First when the body weight is momentarily transferred to one leg, the horizontal and/or parallel lines of pelvic and shoulder in relation to the parallel floor line, must not be upset.

Second, in large movements using extensions and leaps, the shoulder and pelvis lines will lose a degree of their parallel relationship with the floor. However, the balletic concept of placement insists that the horizontal and parallel lines must be regained as soon as the body weight changes to one or both legs" (Lee, 1983, p209-210).

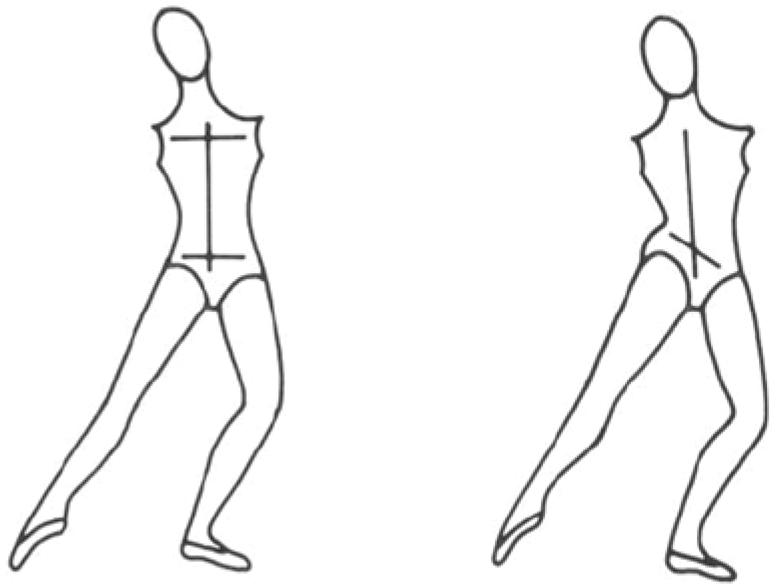
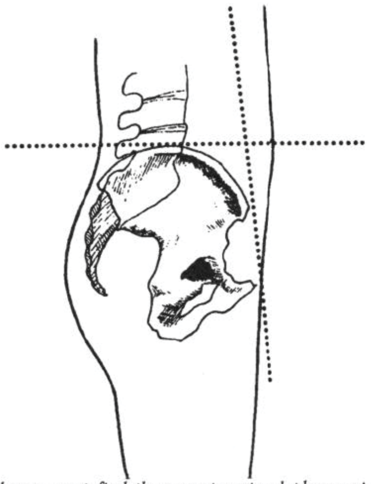


Figure 2.11 *Correct (left image) and incorrect (right image) 'placement' of the pelvis (from Lee, 1983, p209).*

"The dancer must find a correct centered placement for the pelvis. The hip bones are lifted in front, at the back the sacrum is directed strongly downward. The buttocks are held high on the legs, while the lumbar spine remains elongated. When one leg is disengaged from a closed position, an important tenet of ballet training is that the hip crests should remain level and square to the front. In *tendus* to the front and side, the pelvis should remain uninvolved, with the crests absolutely level and facing square to the front" (Grieg, 1994, p41).



A dancer must find the correct centered placement of the pelvis

Figure 2.12 *Centred 'placement' of the pelvis (from Grieg, 1994, p40)*

> "With the abdominal muscles active and the muscles of the buttocks held firmly, vertically align the pelvis block beneath the lower back. Do not allow the buttocks to push or tuck under. Shoulders and hips held horizontal – the right shoulder directly above the right hip and the left shoulder directly above the left hip" (White, 1996, p83).

> "In classical technique the pelvis is kept 'square'. This squareness is controlled by the oblique abdominal muscles on either side of the waist which hold the pelvis in relation to the ribcage. The pelvis is also held 'in balance'. This is controlled by the straight abdominal muscle pulling at the front and the seat muscle pulling down at the back" (Royal Academy of Dance, 1997, p8).

> "When the dancer moves her leg to the front, her hips and shoulders remain (with rare exceptions, square to the *barre*. However, when she moves her leg to the back she opens the working hip but only as much as needed to reveal a fully turned-out leg." (Schorer, 1999, p51).

> "The body must be aligned over the supporting leg and hips and shoulders squared off to each other. Move the leg without a sympathetic motion of the pelvis. By engaging the spine and maintaining an upright pelvis, we ensure that the trapezius and the iliopsoas are optimally positioned to do their work. Maintaining an elongated spine and an aligned pelvis facilitates access to the iliopsoas and enables us to utilise its function of lifting the leg. Even a slight tilting of the pelvis can dramatically affect posture, and most important in our present context, cause the line of gravity to shift back. In an aligned standing body, the pelvis is held upright. This position requires that the pubic bone is held uplifted, creating a connection between the pubis, belly button and the sternum which allows the ASIS to face straight out like a car's headlights. The pelvis remains placed and level when legs are lifted (with the exception of arabesque where a shift forward is allowed. Freedom within the hip joint ensures that the motion of the working leg is isolated from the pelvis and therefore does not result in a sympathetic rotation of the pelvis)" (Paskeva, 2005, p36).

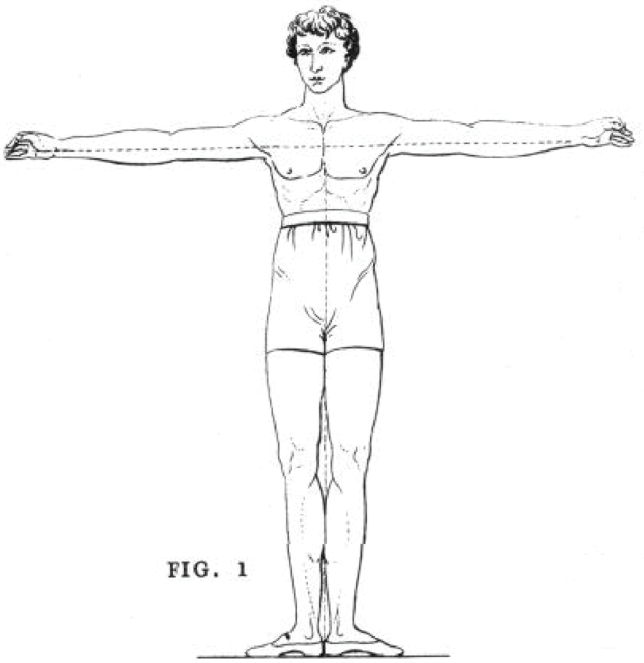
> "Make sure that the shoulders remain square and that the leg moves directly behind" (Walczak and Kai, 2008, p44).

It is clear that the literature has placed considerable emphasis on the positioning of the pelvis. The previous quotations discuss correct pelvic 'placement' with respect to the sagittal, coronal and/or transverse planes. For the purposes of this study, the term 'placement' will therefore be used to define the second key principle of classical ballet technique and will be described as "minimal displacement of the pelvis from a centered position".

2.1.3.3 Turnout

The development and codification of the five positions of the feet made a significant contribution to the advancement of classical ballet technique. This occurred as far back as the 1600s. A significant characteristic of these five positions is that they each require the feet to be placed such that the toes are pointed outwards, *i.e.* turned towards the lateral sides of the body. These "turned-out" positions of the feet developed as a result of the need for ballet dancers to travel sideways on the proscenium stage, without turning their body away from the audience. While much focus was, and still is, placed on the outward rotation of the feet, the structure of the normal human lower limb dictates that if the feet are to be placed in a turned out position then the whole leg must be turned out from the hips (*i.e.* external hip rotation). Thus, for correct execution of the five positions of the feet, a dancer is required to have an ability to externally rotate their hip joint beyond that typically required for normal activities of daily living. Although in inception, turnout was devised as a means of facilitating sideways travel of the body, in the later years of the development of the technique extreme external rotation of the hip joint was found of benefit in allowing greater elevation of the thigh at the hip joint. Rotating the thigh outwards at the hip joint changes the relative position of the greater trochanter of the femur and ilium of the pelvis, thereby allowing greater freedom of the femur at the hip joint. This increased understanding of the structure of the relevant lower limb bones and joints, together with the growing expectation that dancers display extreme flexibility, meant that extreme external rotation of the hip joint became a physical necessity rather than just an aesthetic requirement for classical ballet. High elevation of the legs, with minimal disturbance of the pelvis and thorax in an effort to retain an elegant appearance, is not possible without extreme hip turnout, and for this reason turnout remains a crucial element of classical ballet technique. The following quotations and figures convey the importance of “turnout” in the execution classical ballet technique.

> “The first essential for the legs is to succeed in turning them fully outward. Strive after suppleness in the hips in order that the thigh movements shall be free and the knees well turned out. A dancer whose lower limbs are contracted and who is stiff in the hips gains little esteem, as these defects are always apparent in his execution” (Blasis, 1820, p11).



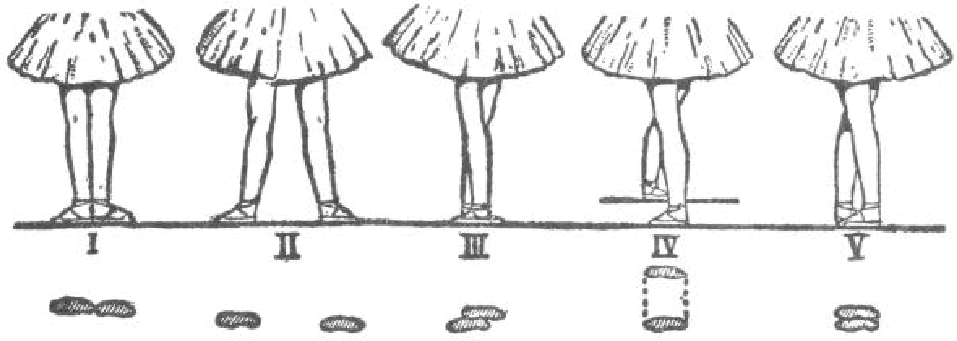
In the first position the legs should be quite straight, the heels close together and the two feet completely turned out to form a straight line.

Figure 2.13 *Turnout (from Blasis, 1828, p12).*

"In the management of your legs, your chief concern must be to acquire a facility of turning them well outwards. Therefore your hips must be free so that your thighs move with ease and your knees turn well outwards. By this means the openings of your legs are rendered easy and graceful." (Beaumont and Idzikowski, 1932, p23).

"The turnout is an anatomical necessity for every theatrical dance. The turnout is the faculty of turning out the knee to a much greater extent than is made possible by nature. The foot turns outward together with the knee. The aim of the turnout is to turn out the upper part of the leg, the hip bone. The result of the turnout is freedom of movement in the hip joint. The turnout enlarges the field of action of the leg. This is the importance of training the legs of a dancer in strict *en dehors* (turnout). It is not an aesthetic conception but a professional necessity. The dancer without a turnout is limited in her movements, while a classical dancer possessing a turnout is in command of all conceivable richness of dance movements of the legs." (Vaganova, 1953, p24).

THE FIVE fundamental positions of the feet are universally known.



2. Positions of the feet

There are five of them because, for turned-out legs, a sixth cannot be found, from which it would be easy and convenient to move.

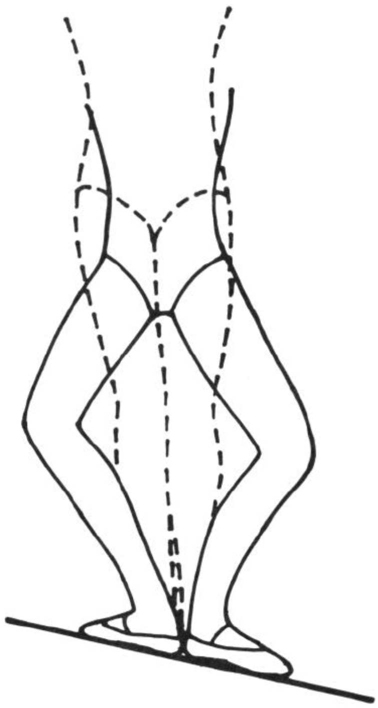
Figure 2.14 *Five positions of the feet (from Vaganova, 1953, p17)*

"The turnout is essential. Trying to turnout from the feet is a mistake which causes rolling over of the big toes. This is turn brings an undue pressure on the cartilage of the knee. It is primarily the thigh that controls the turnout of the leg and when the leg is turned out the feet will follow the lead naturally." (Karsavina 1962, p10).

"The foot should be placed with a turned-out heel, and with the whole leg turned out from the hip joint." (Kostrovitskaya and Pisarev, 1978, p54).

"The turnout must take place within the hip-joints; the knees and thighs are rotated outwards as far as possible so that the feet turn out" (Lawson, 1979, p14).

"Turnout originates in the hip joint and is characterised by the ball and socket (*enarthrosis*) type articulation of its components in which the head of the thigh bone (*femur*) fits into the concavity of the lower part of the pelvis (ilium). Anatomically, turnout is defined as the outward rotation of the entire leg, beginning at the large rounded head of the *femur* within the *acetabulum* cavity of the *ilium*" (Lee, 1983, p210).



Maximum outward rotation of the legs in the hip sockets provides the dancer with freedom to move quickly in all directions.

Figure 2.15 *Turnout – "Maximum outward rotation of the legs in the hip sockets" (from Lee, 1983, p211)*

"Classical ballet is based on the turnout; without it, the technique cannot exist. Far from being primarily an aesthetic concept, the turnout has a profoundly functional role. The well turned-out leg makes a fundamental contribution to the stability, range of motion, mobility and strength of the dancer, as well as to the elongated shape of the muscles. The rotation of the thigh bone in the hip socket is a movement, it is an action that the dancer takes, an action that must be learned and practiced. Visibly the results take place in the thigh just below the pelvis, and continue into the knee, ankle and foot. The whole leg is rotated as one, and the relationship of each part to the others remains the same as when the leg is in a neutral position. The turnout allows the dancer to move with equal ease in any direction" (Grieg, 1994, p53-54).

Figure 2.16 *Turnout – "turnout is a movement"*
(from Grieg, 1994, p53)

"Turn out refers to an outward rotation of the entire leg, not just the feet. Turnout is the result of combining the basic stance, with a level pelvis block, upward lifting abdominal muscles, firm buttocks, and an outward rotation of the thigh muscles at the hip joint. While simultaneously straightening knees, ankles, and feet, this graceful outward rotation of thigh muscles is designed to facilitate the multitude of ballet poses and positions and also to maintain stability and poise during sudden changes of direction while in motion. Finally, turnout helps make the many poses and positions more aesthetically pleasing. Turnout helps stabilise the torso laterally. It allows for quick, controlled changes of direction. It is one of the basic ingredients of the basic stance" (White, 1996, p85-86).

"The use of turnout is fundamental. The external rotation of the hip is controlled by the gluteus maximus (the main seat muscle), and the small rotators which are the deepest muscles in the gluteal area, and most importantly the adductors, or the inner thigh muscles. With this action, the rest of the leg rotates and the foot is held in turnout that corresponds with that of the hip" (Royal Academy of Dance, 1997, p9).

"In all positions, Balanchine wanted to see the turnout developed from the hip down. The legs are rotated out from the hips, with inside thighs, calves and heels brought forward." (Schorer, 1999, p40).

> "Turnout of the legs contributes to the ballet "look". Turnout always begins in the hip joint, with the rest of the leg in alignment. Turnout came into practice when it became clear that the outward positioning of the feet, accompanied by the femoral rotation, provide more stability and was also shown to allow more mobility when the legs were raised. Turnout will gradually increase until, by the fourth year a full opening of 90 degrees is possible. When the turnout is firmly held in the hip joint, a further outward movement at the ankle joint can be expected. Mobility in the ankle allows the foot to be 'winged'." (Paskeva, 2002, p 14).

> "The knees and thighs are to be completely turned out and facing side. The heel of the supporting foot must remain very turned out" (Walczak and Kai, 2008, p27 & p109).

The preceding references show that turnout is a key feature of classical ballet technique. The literature reveals that turnout has both an aesthetic and a functional purpose in the execution of classical ballet technique. For this study, "turnout" has been identified as the third fundamental principle of the technique, and is defined as "maximum external rotation of lower limbs".

2.1.3.4 <u>*Extension*</u>

The final phase Hammond and Hammond (1979) identified in the development of classical ballet technique was described as "maximum linear extension". This development saw ballet dancers acquire extreme flexibility and length of line throughout their entire body. This aesthetic had already been established very early in the development of the technique (*i.e.* grand manners). With the introduction of *pointe* work during the Romantic period it meant that straight ("extended") knee and ankle joints of the supporting leg had already been identified as essential requirements to achieve balance *en point.* However, it was not until the early 20th century that dancers were expected to raise their 'working' leg to extreme heights, while also maintaining maximum extension of the knee and ankle joints. At this time the typical physique of professional female ballet dancers changed to become more lean and lithe, and the required aesthetic was one of length and purity of line, as opposed to the more soft and rounded appearance of dancers in the preceding Romantic era. The following quotations and figures depict the importance of the full extension of the knee and ankle joint in achieving maximum length and line in classical ballet technique.

“The movement of the knees is inseparable from that of the instep, it is incomplete unless the leg is extended and the toes forced downward. A person with knees inclined to be bowed should endeavour to overcome his natural stiffness by constant practice in stretching to render them more supple. He will never make a really successfully danseur noble” (Blasis, 1820, p12 & p15).

Figure 2.17 *Leg ‘extension’ (from Blasis, 1820, p18).*

“Pay great attention to your insteps. Do not let them relax either in strength or elasticity. In forcing your insteps, keep the *pointe* extended. The movement of the knee is inseparable from that of the instep, it is perfect only when the knee is extended. The foot and the knee must remain perfectly straight and be extended to the utmost” (Beaumont & Idzikowski, 1932, p23-24).

“The legs must be extended energetically. The legs must be forcefully extended in the knees, arches and toes. Speaking of the execution of all classic *pas*, it must be remembered that they are all done with the toes and arches extended. The leg on which the dancer stands should be fully extended, like a taut string.” (Vaganova, 1953, p29).

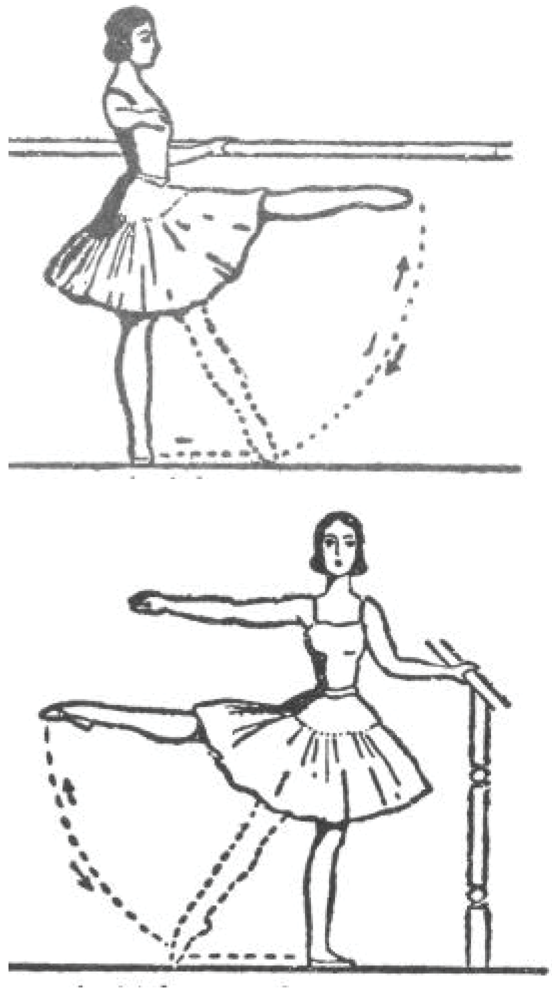


Figure 2.18 *Leg 'extension' (from Vaganova, 1953, p29-30)*

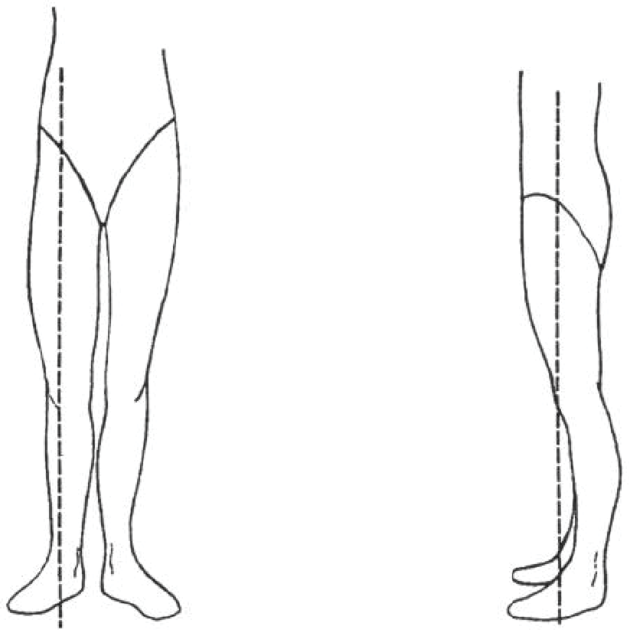
"The tension of muscles must be complete and must go through the whole of the leg: instep, calf and thigh. The knee and thigh of the supporting leg must be very taut, so as not to give away even slightly under the upward thrust of the working (lifting) leg. The inability to straighten the knee completely, or having what might be called a knobbly knee, is a problem. The knee should be tensed while lifting the leg" (Karsavina, 1962, p16).

"The arch of the foot is strongly developed and strengthened, and the leg acquires a beautiful and finished line. The supporting leg must be strongly stretched." (Kostrovitskaya and Pisarev, 1978, p71).

"The dancer must know the feeling of a fully stretched leg. No matter what degree of turnout is attempted it must be ensured that the centre of the knee, ankle and middle toes are in the same straight line." (Lawson, 1979, p27).

"The straight line of the leg from hip to toe results in the functional and aesthetic elements necessary to classical ballet. In the various forms of *battement*, the knee, ankle and metatarsal joints are trained out of their natural inclination to flex or relax. The knee and ankle joint must learn to become fully extended to form a taut leg." (Lee, 1983, p230).

"If you view the body from the front, you should be able to draw an imaginary line through the centre of the hip socket and continue down slightly forward of the centre of the knee joint (because of the dancer's slightly forward stance), and on into the foot, just in front of the ankle. The dancer must stand on straight legs with well braced thigh muscles and kneecaps that are lifted by the quadriceps. Correct alignment through the centre of the ankle to the second toe must be maintained at all times. It is vital that the joints between the phalanges remain extended, there must be no hint of "clawing" the toes." (Grieg, 1994, p88-89 & p103).



Viewed from the front, a plumb line would fall through the center of the hip, knee and ankle joints

Viewed from the side, the plumb line would fall slightly forward of the center of the knee joint and just in front of the ankle

Figure 2.19 *Leg 'extension' (from Grieg, 1994, p88)*

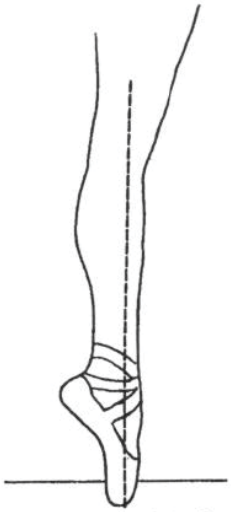


Figure 2.20 *Leg 'extension'*
(from Grieg, 1994, p105)

"Although the legs must be held straight, the knee joints must not be allowed to lock at their rearward extreme. The knee should help form and control a straight leg line extending from the ankle to the pelvis." (White, 1996, p83).

"In every stretched position, there is a straight line running from the centre of the knee cap, between the ankle bones, and along the foot between the 2nd and 3rd toes" (Royal Academy of Dance, 1997, p28).

"Balanchine wanted to see that stretch from the top of the hip to the tips of the toes. Every part of the stretched, straight leg lifted off the floor contributed to making the look he wanted to see; stretched knee and a strong and well shaped *pointe*." (Schorer, 1999, p44).

"Classical line is characterised by its length, purity and simplicity. The feet are pointed to create the illusion of a longer leg. Anything that detracts from the purity of the line can be termed 'unclassical'." (Paskeva, 2002, p12).

"Don't look like a dwarf. Pull up and straighten knees completely (Walczak and Kai, 2008, p64).

The ability to completely extend the knee and ankle joints to created a straight line through the lower limb has been highlighted in many ballet texts as a crucial component of correct classical ballet technique. The extent to which a dancer can extend their knee and ankle joints is genetically determined by the bony structure of their joints, and as such this factor has proven to be one of the deciding physical factors in selection for a professional career as a ballet dancer. For this project, the final fundamental principle of classical ballet technique has been identified as ‘extension’, and is defined as “maximum elongation of the lower limbs”.

2.1.3.5 Summary of the Fundamental Principles of Classical Ballet Technique.

After careful review of the history of the development of classical ballet technique, and consideration of the extensive dance literature sources spanning many centuries, a succinct list of fundamental principles of classical ballet technique has been developed. The fundamental principles of classical ballet technique, and their defining characteristics have thus been identified as a follows:

1) ‘Alignment’ - maintaining verticality of the torso
2) ‘Placement’ - minimal displacement of the pelvis from a centred position
3) ‘Turnout’ - maximum external rotation of lower limbs
4) ‘Extension’ - maximum elongation of the lower limbs

In Section 2.1.1 of this literature review, classical ballet “technique” was defined as “the way in which the limbs and body segments are oriented with respect to each other while performing the movement”. The four key principles of classical ballet “technique” identified through this literature review relate well to this definition of technique. Each principle is based on the position of the limbs and body segments, and can therefore be described as a kinematic characteristic. Kinematic variables of the human body and human motion can be quantitatively measured using various form of instrumentation, and can also be qualitatively analysed through visual observation with the human eye. The next section will review the academic literature to investigate the extent to which the biomechanical characteristics of various theatrical dance forms, including classical ballet, have been assessed through quantitative means. Later sections of the literature review will focus on the accuracy and reliability of qualitative analysis (*i.e.* visual observation) in assessment of various forms of human movement.

2.2 Quantitative Biomechanical Analysis in Dance

2.2.1. Introduction

Investigation of the biomechanical properties of human movement involves quantification and analytical description of body movement patterns, as well as measurement of the associated forces and muscle activity that contribute to the movement. The type of data collected and assessed during quantitative biomechanical analysis generally fall into one of only a few categories: kinematic data; kinetic data; and electromyographic data. Kinematic data provide information on individual joint or segment motion, as well as overall whole body movement, while kinetic data describe the mechanical forces, torques/moments and powers that cause the resultant motion. Electromyography (EMG) enables measurement of the electrical activity of individual muscles, and/or muscle groups.

Over the past 40 to 50 years there has been much scientific research conducted on the biomechanics of human movement in relation to clinical and sporting aspects of human motion. Due to the development of more efficient and accurate measurement techniques, instrumented clinical gait analysis is being used increasingly in hospitals throughout the world to assist with clinical decision making. A great deal of scientific research is published in this area every year, with the aim of further improving measurement methods and data reliability and validity. Similarly, there is much interest in quantitative sports biomechanics. Throughout the past few decades this area of research has been given the opportunity to grow and develop within the scientific community through the interest and support offered by various sporting organisations. In comparison to research conducted in the clinical setting and sporting arena, quantitative instrumented biomechanical assessment in dance is in its relative infancy as a field of research. A review of published scientific literature in this field has revealed that although a few quantitative studies in dance biomechanics were conducted during the 1970s, 1980s, and 1990s, the vast majority of research in this area has occurred from 2000 onwards, with a considerable increase in publications since 2005.

References were selected for inclusion in this literature review if they consisted of a full article published in an academic journal, and if the study protocol involved instrumented quantitative measurement of biomechanical properties of dance-specific or dance-related movements performed by trained dancers. A total of 75 scientific references were selected and examined as part of this literature review.

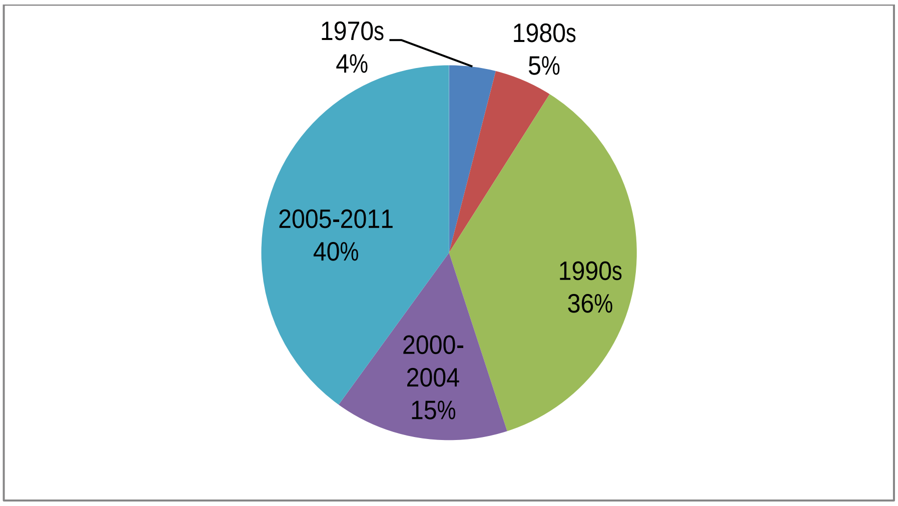


Figure 2.21 *Summary of publication years of quantitative dance biomechanics research*

2.2.2. Instrumentation Used in Quantitative Dance Biomechanics Research

Of the 75 articles selected for inclusion in the review, 3 (4%) were published during the 1970s, 4 (5%) during the 1980s, 27 (36%) during the 1990s, and the majority, 41 (55%), have been published since 2000. The significant increase in publication of dance biomechanics literature that has occurred over the past decade has been coincident with a shift in the methodological processes and instrumentation used by researchers. Early researchers relied on photography (Hinson *et al.*, 1978; Laws, 1979) and motion picture film cameras (Ryman, 1978) combined with tracing techniques, to collect and analyse two-dimensional (2D) kinematic data of selected dance movements. The 1980s saw the introduction of the use of digitised video data to obtain 2D kinematic data (Laws, 1986; Laws and Lee, 1989). Use of this method of dance analysis continued into the 1990s (McNitt-Gray *et al.*, 1992; Dozzi and Winter, 1993; Midgett, 1993; Rasmussen and Hay, 1993; Simpson *et al.*, 1996; Krasnow and Chatfield, 1997; Simpson and Kanter, 1997), however computerised motion analysis, either 2D (Mouchnino *et al.*, 1992; Mouchnino *et al.*, 1998; Gamboian *et al.*, 1999) or 3D (Chatfield, 1996), also grew in its usage during this decade. Since 2000, computerised motion analysis has become the most commonly used method for obtaining kinematic and kinetic data related to analysis of dance movements, with a clear trend towards increased use of 3D techniques (Wilmerding *et al.,* 2003; Masso *et al.,* 2004; Thullier and Moufti, 2004; Wilson *et al.,* 2004; Lin *et al.,* 2005; Shan, 2005; Lepelley *et al.*, 2006; Chatfield *et al.,* 2007; Hagins *et al.,* 2007; Kwon *et al.,* 2007; Wilson *et al.,* 2007; Pappas and Hagins, 2008; Golomer *et al.,* 2008; Golomer *et al.,* 2009a; Golomer *et al.,* 2009b; Alderson *et al.,* 2009; Orishimo *et al.,* 2009; Bertucco and Cesari, 2010; Mayers *et al.,* 2010; Shippen and May, 2010; Bronner and Ojofeitimi, 2011; Kulig *et al.,* 2011) compared to 2D techniques (Gamboian *et al.,* 2000; Bronner *et al.,* 2002; Bronner and Ojofeitimi, 2006). 2D (Couillandre *et al.,* 2008) and 3D (Beijjani *et al.,* 1990; Feipel *et al.,* 2004) electrogoniometers have also been used as a means to collect kinematic data by a few researchers in dance biomechanics.

Use of instrumented force plates for analysis of dance movements also increased during the 1990 and 2000s. Some of these studies were interested in examining dancers' balance and stability by obtaining information on movement of the centre of pressure (Perrin *et al.,* 2002; Simmons, 2005b), while others (Dozzi and Winter, 1993; Simpson *et al.,* 1996; Simpson and Pettit, 1997; Lin *et al.,* 2005; Kwon *et al.,* 2007; Hagins *et al.,* 2007; Imura *et al.,* 2008; Alderson *et al.,* 2009; Orishimo *et al.,* 2009; Shippen and May, 2010; Imura *et al.,* 2010; Kulig *et al.,* 2011) used force plate data, in combination with kinematic data, to calculate kinetic variables such as joint reaction forces, torques/moments and/or powers. A few authors (Miller *et al.*, 1990; McNitt-Gray *et al.*, 1992; Laws and Petrie, 1999; Harley *et al.*, 2002; Dworak, 2005; Hagins *et al.*, 2007; Chockley, 2008; Alderson *et al.*, 2009; Orishimo *et al.*, 2009; Shippen and May, 2010; Bruyneel *et al.*, 2010; Kulig *et al.*, 2011) have used force plates to present data on the ground reaction forces associated with various dance movements.

Electromyography (EMG) has also been used for investigation of some of the motor control and coordination mechanisms typically used in theatrical dance styles. Some researchers in dance biomechanics were using EMG as early as the 1970s (Ryman and Ranney, 1979), but it wasn't until the 1990s (Mouchnino *et al.*, 1992; Chatfield, 1993; Trepman *et al.*, 1994; Chatfield, 1996; Trepman *et al.*, 1998; Ravn *et al.*, 1999) and 2000s (Wilmerding *et al.*, 2001; Harley *et al.*, 2002; Masso *et al.*, 2004; Simmons, 2005a;

Lepelley *et al.,* 2006; Hagins *et al.,* 2007; Chatfield *et al.,* 2007; Couillandre *et al.,* 2008; Bertucco and Cesari, 2010), that EMG was used more widely amongst dance science researchers.

Although not used widely, other instrumented measurement techniques that have been utilised for dance biomechanics research include pressure plates, either insole (Fiolkowski and Bauer, 1997) or external (Miller *et al.,* 1990; Albers *et al.,* 1992), and accelerometers (Voloshin *et al.,* 1989; Golomer *et al.,* 1999; Guillou *et al.,* 2007; Couillandre *et al.,* 2008).

2.2.3. Purpose and Aims of Quantitative Dance Biomechanics Research

As indicated in the previous sections, the prevalence of dance biomechanics research has increased considerably since its early days of the 1970s, with as much as 40% of the published work being conducted since 2005. Various instrumentation techniques have been used, with the aim of answering a variety of questions related to understanding the biomechanical mechanisms associated with the execution of theatrical dance steps. Review of the literature reveals that, in terms of the specific aims and purpose of each study, there are a few distinct categories that dance biomechanics academic literature can be assigned to.

Many studies have focused on providing a biomechanical description of dance movements. In fact, over one third (36%) of the studies included in the literature review were placed in this category. The authors of these studies have attempted to provide detailed quantitative descriptions of the ways in which dance movements are executed in an effort to inform dancers and dance instructors about the most efficient or skilful way to perform a movement. It can be clearly noticed that the instrumentation used in each study relates closely to the aim of the study, and as such the majority of studies (74%) that aimed to provide a 'biomechanical description' have obtained kinematic data consisting of displacements, velocities and accelerations. The most commonly presented data types were relative or 'local' 3D joint angles (Beijjani *et al.,* 1990; Masso *et al.,* 2004; Lin *et al.,* 2005; Wilson *et al.,* 2007; Bronner and Ojofeitimi, 2011), and 'local' 2D joint angles (Hinson *et al.,* 1978; Ryman and Ranney, 1979; Trepman *et al.,* 1994; Trepman *et al.,* 1998; Bronner and Ojofeitimi, 2006; Couillandre *et al.,* 2008). Absolute or 'global' segment kinematics have also been obtained (Ryman and Ranney, 1979; Woodhull-McNeal *et al.*, 1990; Midgett, 1993; Golomer and Fery, 2001; Wilson *et al.*, 2004; Bronner and Ojofeitimi, 2006; Wilson *et al.*, 2007; Bronner and Ojofeitimi, 2011), as well as whole body or centre of gravity kinematic data (Laws, 1979; Laws, 1986; Laws and Lee, 1989; Laws and Fulkerson, 1992; Rasmussen and Hay, 1993; Midgett, 1993). A few studies in the 'biomechanical description' category reported kinetic data, such as joint or segment torques/moments (Lin *et al.,* 2005; Kwon *et al.*, 2007; Imura *et al.,* 2008), while some presented EMG data, either in conjunction with kinematic data (Ryman and Ranney, 1979; Trepman *et al.*, 1994; Trepman *et al.*, 1998; Masso *et al.,* 2004; Couillandre *et al.,* 2008), or as the only data type (Wilmerding *et al.,* 2001). Only two studies (Laws and Petrie, 1999; Chockley, 2008) used ground reaction force data obtained from a force plate to provide a 'biomechanical description' of dance movements.

Dance science and medicine researchers have also been interested in investigating any links or associations of dance movements with injury. Upon review of the studies interested in injury, it is also clear that the study aims reflect the instrumentation used and data type presented. Eighteen studies (24%) were identified as having an aim of looking at 'injury link', and of these, 11 (61%) used a force plate to obtain data. The most commonly presented data type calculated from the force plate measurements were joint reaction forces (Dozzi and Winter, 1993; Simpson and Kanter, 1997; Simpson and Pettit, 1997; Alderson *et al.,* 2009; Mayers *et al.,* 2010; Shippen and May, 2010), joint reaction torques/moments (Dozzi and Winter, 1993; Simpson and Kanter, 1997; Simpson and Pettit, 1997; Orishimo *et al.*, 2009; Mayers *et al.*, 2010; Kulig *et al.*, 2011) and ground reaction forces (McNitt-Gray *et al.*, 1992; Dworak, 2005; Orishimo *et al.*, 2009; Alderson *et al.*, 2009; Mayers *et al.*, 2010; Shippen and May, 2010; Kulig *et al.*, 2011). Only a few studies used kinematic data alone, obtained either from computerised motion analysis (Bronner *et al.*, 2002; Shan, 2005), digitised video data (Barnes *et al.,* 2000), accelerometry (Voloshin *et al.,* 1989), or electrogoniometry (Feipel *et al.,* 2004), to investigate possible associations of dance movements with musculoskeletal injury. It should also be noted that with respect to the studies interested in identifying any links between dance and musculoskeletal injury, the majority of studies have analysed high impact movements (*i.e.* jumps) or high pressure movements (*i.e. en pointe*). For example, the *grande jeté* (split leap) has received attention in the literature (Simpson *et al.*, 1996; Simpson and Kanter, 1997; Simpson and Pettit, 1997; Shan, 2005; Kulig *et al.*, 2011), as have other dance jumps involving either springing from two feet (McNitt-Gray *et al.*, 1992) or from one foot (Dworak, 2005; Orishimo *et al.*, 2009). Concerns have been raised about the level of pressure and force that dancers' feet are subjected to while dancing on their toes in *pointe* shoes (*en pointe*). Teitz *et al.* (1985) measured the peak pressure on the first and second toes when *en pointe* in *first position,* and Albers (1992) measured the peak plantar pressure when dancing on a flat foot and when dancing *en pointe* with the body weight supported by a single leg or double leg. Dozzi and Winter (1993) measured the joint reaction forces and torques/moments at the ankle joint when *en pointe* in *second* position. The biomechanical properties of high impact styles of dance such of flamenco (Voloshin *et al.,* 1989), tap (Mayers *et al.,* 2010) and Irish dance (Shippen and May, 2010) have also been examined with respect to their possible association with musculoskeletal injury.

A third purpose or aim of the research studies included in this literature review was identified as that of investigating aspects of 'motor control'. Electromyographic (EMG) data in combination with kinematic data, were most commonly used for the 19 studies placed in this category. These studies looked at the muscle activation patterns of either multiple (Mouchnino *et al.,* 1992; Ravn *et al.,* 1999; Lepelley *et al.,* 2006; Chatfield *et al.,* 2007) or single (Chatfield, 1996; Harley *et al.,* 2002; Bertucco and Cesari, 2010) muscles. Some studies used only kinematic data in their investigations of 'motor control' (Mouchnino *et al.,* 1998; Golomer *et al.,* 1999; Thullier and Moufti, 2004; Guillou *et al.,* 2007; Golomer *et al.,* 2008; Golomer *et al.,* 2009a; Golomer *et al.,* 2009b), and only two studies (Chatfield, 1993; Simmons, 2005a) reported EMG data alone. Centre of pressure (Perrin *et al.,* 2002; Mouchnino *et al.,* 1992; Simmons, 2005b) and ground reaction force (Harley *et al.,* 2002; Bruyneel *et al.,* 2010) data were also used to study 'motor control'. Interestingly, most of the studies that looked at 'motor control' analysed movements that were not actually dance movements (Perrin *et al.,* 2002; Mouchnino *et al.,* 1992; Mouchnino *et al.,* 1998; Golomer *et al.,* 1999; Ravn *et al.,* 1999; Harley *et al.,* 2002; Thullier and Moufti, 2004; Simmons, 2005b; Simmons, 2005a; Lepelley *et al.,* 2006; Chatfield *et al.,* 2007; Guillou *et al.,* 2007; Bruyneel *et al.,* 2010; Bertucco and Cesari, 2010), however these studies have been included in the review because each study contains a group of trained dancers as subjects. These studies investigated 'motor control' by comparing the movement and coordination strategies of highly skilled movement practitioners, such as dancers, and in some cases gymnasts (Thullier and Moufti, 2004; Guillou *et al.*, 2007) and martial artists (Perrin *et al.*, 2002), with those of untrained controls. The movements investigated included quiet standing (Perrin *et al.*, 2002; Simmons, 2005b; Simmons, 2005a), leg raises (Mouchnino *et al.*, 1992; Mouchnino *et al.*, 1998; Thullier and Moufti, 2004; Lepelley *et al.*, 2006; Bertucco and Cesari, 2010), jumps (Ravn *et al.*, 1999; Harley *et al.*, 2002) and balancing on a see-saw platform (Golomer *et al.*, 1999; Guillou *et al.*, 2007). Only a few studies in the 'motor control' category assessed dance movements. A series of studies by Golomer *et al.* (2007; 2008; 2009) used 3D kinematic data to compare the 'motor control' abilities of trained dancers and untrained controls in performing a *pirouette* (a whole body turn on one leg). The dancers were instructed to perform a "*pirouette*" and the controls a "turn on one leg as they naturally would". Only a few studies looked at the 'motor control' abilities of dancers alone, and in most of these studies 'motor control' of different groups of dancers was analysed and compared with respect to the dancers' age (Bruyneel *et al.*, 2010), or skill level (Lepelley *et al.*, 2006; Chatfield *et al.*, 2007). Chatfield (1993) didn't compare different groups of dancers, but simply presented EMG data for seven advanced college dancers during their execution of several ballet movements (*pliés, relevés, developpés, grand battement, sautés*).

A few dance biomechanics research studies have attempted to investigate the efficacy or usefulness of specific dance training programs or regimes. To do this, these studies have collected quantitative data before and after implementation of a training program. Kinematic variables were used as the outcome measure for all seven studies in this category. Specifically, authors obtained "before" and "after" data using 2D (Gamboian *et al.*, 1999; Gamboian *et al.*, 2000) or 3D (Wilmerding *et al.*, 2003) motion analysis data, 2D digitised video data (Krasnow and Chatfield, 1997; Deckert *et al.*, 2007; Holt *et al.*, 2011) or centre of gravity kinematic data calculated from ground reaction force data (Poggini *et al.*, 1997). Interestingly, six of the seven articles that aimed to measure the effects of training programs, analysed ballet movements, and five of the studies were specifically interested in assessing pelvic anterior/posterior tilt (Gamboian *et al.*, 1999; Gamboian *et al.*, 2000; Wilmerding *et al.*, 2003; Deckert *et al.*, 2007; Holt *et al.*, 2011).

There was also similarity between the studies in this category with respect to the type of movements analysed, with five studies (Krasnow and Chatfield, 1997; Gamboian *et al.*, 1999; Gamboian *et al.*, 2000; Deckert *et al.*, 2007; Holt *et al.*, 2011) measuring the biomechanical characteristics of the *plié* (*i.e.* knee bend).

A less common, yet also very important, study purpose that was identified was that of 'effect of dance shoe or surface'. Only a few studies (Miller *et al.*, 1990; Fiolkowski and Bauer, 1997; Hagins *et al.*, 2007; Pappas and Hagins, 2008) investigating this area have been published. Two of these (Miller *et al.*, 1990; Fiolkowski and Bauer, 1997) measured peak plantar pressure. Miller (1990) looked at the role that modification of dance shoes has on peak plantar pressure in professional ballet dancers, and Fiolkowski and Bauer (1997) studied the effects of different floor surfaces on plantar pressure in student dancers. Hagins *et al.* (2007) and Pappas and Hagins (2008) both investigated the effects of a "raked" (*i.e.* inclined) stage on the movement patterns of professional musical theatre dancers while performing a bilateral drop jump (Hagins *et al.*, 2007), or while standing still (Pappas and Hagins, 2008). Both these studies used 3D motion analysis to obtain lower limb joint angle data, and Hagins *et al.* (2007) also used a force plate to measure the direction and magnitude of the ground reaction forces associated with landing a jump onto an inclined surface.

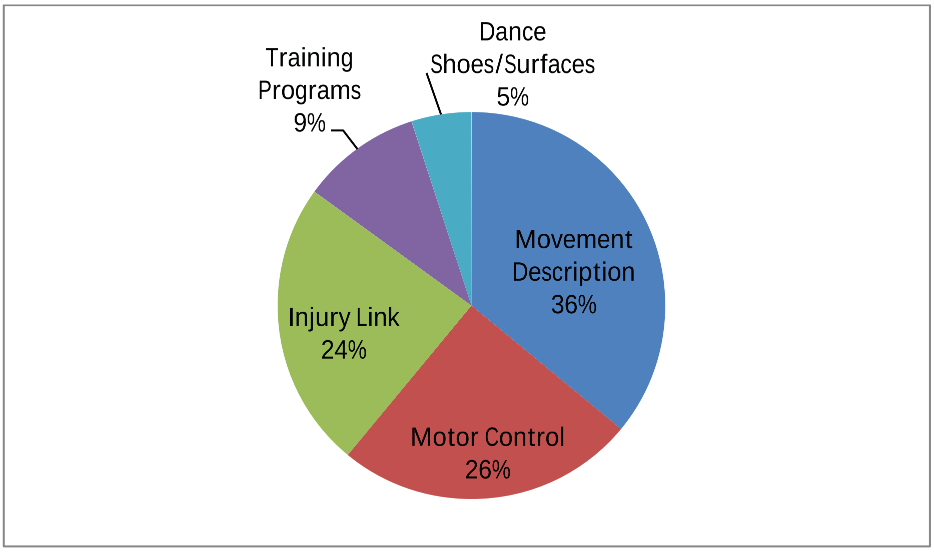


Figure 2.22 *Summary of study purposes of quantitative dance biomechanics research*

2.2.4. Dance Genres and Quantitative Dance Biomechanics Research

There are many different genres or styles of dance, and it is interesting to examine which of these styles have received the most attention in terms of quantitative dance biomechanics research. The academic literature indicates that the biomechanical characteristics of classical ballet have been analysed most frequently. Of the 75 articles included in this literature review, 46 (62%) have analysed classical ballet movements. Perhaps it is the consistency, universality and strong tradition of the technique of classical ballet lending itself well to systematic research that has brought about this large proportion of ballet-related biomechanics research. Or indeed it could be that the extreme and somewhat unnatural physical requirements of the art form create a stronger interest in the biomechanical properties of classical ballet technique.

Other dance genres that have been researched with respect to quantitative biomechanics are modern dance (McNitt-Gray *et al.*, 1992; Chatfield, 1996; Simpson *et al.*, 1996; Simpson and Kanter, 1997; Simpson and Pettit, 1997), flamenco (Voloshin *et al.*, 1989; Beijjani *et al.*, 1990), tap dance (Mayers *et al.*, 2010) and Irish dance (Shippen and May, 2010). With the exception of Chatfield (1996), all of the studies on modern dance attempted to address how the particular movements may be associated with potential injury. 2D digitised video data and force plate data were used to assess this, with authors reporting joint reaction forces (Simpson *et al.*, 1996; Simpson and Kanter, 1997; Simpson and Pettit, 1997) or ground reaction forces (McNitt-Gray *et al.*, 1992). Chatfield (1996) presented kinematic data obtained from 3D motion analysis, together with EMG data, to examine the potential injury risks associated with advanced college dancers performing a modern dance sequence. Specifically, their onset of abdominal muscle activity was measured in relation to their ankle and wrist linear displacements.

The studies that analysed flamenco, tap, and Irish dance movements were all interested in identifying and measuring biomechanical parameters that may be associated with injury risk. In relation to flamenco dance, Voloshin *et al.* (1989) used accelerometers to measure the accelerations of the anterior superior iliac spines (ASIS) and tibial tuberosity with and without insoles in the shoes, and Beijjani *et al.* (1990) used 3D electromagnetic goniometers to measure the flexion/extension and lateral bending angles of the thoracic and lumbar spine. Very recently, Mayers *et al.* (2010) used 3D motion analysis and force plate data to calculate the hip, knee, and ankle joint reaction forces and torques/moments, and vertical ground reaction forces associated with professional level tap dancing. Using similar instrumentation, Shippen and May (2010) reported joint contact forces, muscle loading estimates (gastrocnemius & soleus), and ground reaction force data, for professional female Irish dancers performing the 'Rock' step.

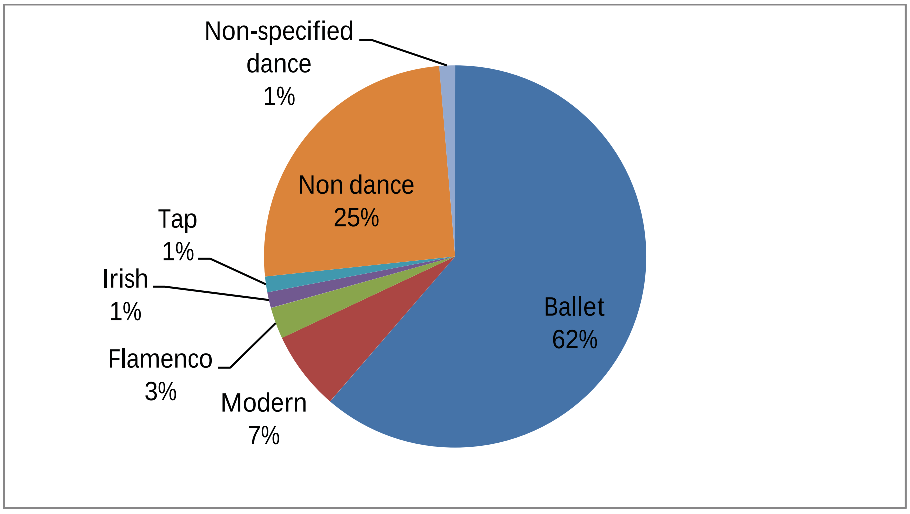


Figure 2.23 *Summary of dance genres analysed in quantitative dance biomechanics research*

Sixty-two percent (62%) of the studies included in this literature review have analysed the biomechanical properties or characteristics of classical ballet technique. Since this research thesis is primarily concerned with analysis of classical ballet technique, the following subsection will focus in more detail on the academic literature that relates specifically to quantitative measurement of classical ballet technique.

2.2.5. Quantitative Biomechanics Research in Classical Ballet Technique

As detailed in Section 2.2.4, a large proportion, 46 (62%), of the dance biomechanics articles included in this literature review have been concerned with quantitative analysis of classical ballet movements. The year of publication of these studies spans from 1978 through to 2011, with 54% of the research conducted since 2000. In terms of the purpose of these studies, the majority (54%) of studies aimed to provide a quantitative 'movement description', 22% focused on examining possible 'links with injury', 13% investigated the 'effect of training programs', 9% analysed aspects of 'motor control', and only one study (2%) was concerned with the biomechanical 'effects of dance shoes and/or surfaces'.

2.2.5.1 Instrumentation Used in Quantitative Biomechanical Analysis of Ballet Technique

With respect to the instrumentation used, as was the case when reviewing all dance biomechanics studies, kinematic analysis was also found to be the most commonly used method for biomechanical assessment when examining classical ballet technique. Seventy four percent (74%) of studies presented 2D or 3D kinematic data, and of these, 60% used 2D techniques and 40% used 3D techniques. There was more variability in the types of techniques used for 2D analysis than for 3D analysis. As indicated in Section 2.2.2, the year of publication has influenced the instrumentation used. Most of the earlier studies used simplistic, yet time consuming, 2D techniques such as photography and tracing (Hinson *et al.,* 1978; Laws, 1979), and video and motion photography (Laws, 1986; Laws and Lee, 1989). Use of video and digitisation of ballet movements increased in the 1990s, (Woodhull-McNeal *et al.,* 1990; Midgett, 1993; Rasmussen and Hay, 1993; Dozzi and Winter, 1993; Krasnow and Chatfield, 1997; Barnes *et al.,* 2000), however this 2D technique has also been used in more recent studies (Deckert *et al.,* 2007; Holt *et al.,* 2011). Other 2D kinematics techniques that have been used to assess the biomechanics of classical ballet include goniometers (Trepman *et al.,* 1994; Trepman *et al.,* 1998; Feipel *et al.,* 2004; Couillandre *et al.,* 2008), and 2D computerised motion analysis (Gamboian *et al.,* 1999; Gamboian *et al.,* 2000; Bronner *et al.,* 2002; Bronner and Ojofeitimi, 2006). Since 2004, the majority of the quantitative studies on the kinematics of classical ballet have used 3D motion analysis (Wilson *et al.,* 2004; Masso *et al.,* 2004; Lin *et al.,* 2005; Shan, 2005; Wilson *et al.,* 2007; Golomer *et al.,* 2008; Golomer *et al.,* 2009a; Golomer *et al.,* 2009b; Alderson *et al.,* 2009; Kulig *et al.,* 2011; Bronner and Ojofeitimi, 2011). Prior to 2004, there were no published articles that used 3D motion analysis to assess classical ballet movements.

A few studies (Dozzi and Winter, 1993; Lin *et al.,* 2005; Kwon *et al.,* 2007; Imura *et al.,* 2008; Imura *et al.,* 2010; Kulig *et al.,* 2011) have presented kinetic data, such as joint reaction forces and/or torques/moments, for the lower limb in classical ballet, however there is no published data on joint reaction powers. Some studies have reported EMG data, either as the only data type (Chatfield, 1993; Wilmerding *et al.,* 2001), or in conjunction with kinematic data (Ryman and Ranney, 1979; Trepman *et al.,* 1994; Trepman *et al.,* 1998; Masso *et al.,* 2004; Couillandre *et al.,* 2008), and only two studies

(Dworak, 2005; Chockley, 2008) have looked specifically at the ground reaction forces associated with classical ballet.

2.2.5.2 Quantitative Biomechanical Analysis of the Seven Movements of Classical Ballet

It is also interesting to consider the types of ballet movements or "steps" that have been studied in quantitative biomechanics research. The steps that have been analysed will be considered in terms of the 'Seven Movements of Dance', as defined by Noverre (1760). The most widely researched ballet movement to date has been the 'bend' (*plié*). One of the most fundamental movements in ballet, the *plié* is a movement in which the upright torso, spine, and pelvis are stabilised as they are lowered with coordinated hip and knee flexion, and then raised back to the starting position with hip and knee extension (Gantz, 1990). Repeated execution of the *plié* in training class is used to improve strength, timing, alignment, trunk stability, and coordination of joint movement (Gantz, 1990). The *plié* is also often the first component of other movements such as the *relevé* (*i.e.* rising on the toes), *pirouettes* (*i.e.* turns of the body), and jumps. In total, ten articles have published quantitative data on the biomechanics of the *demi plié* (Chatfield, 1993; Trepman *et al.*, 1994; Gamboian *et al.*, 1999; Gamboian *et al.*, 2000; Deckert *et al.*, 2007; Couillandre *et al.*, 2008; Holt *et al.*, 2011) and/or *grand plié* (Krasnow and Chatfield, 1997; Trepman *et al.*, 1998; Barnes *et al.*, 2000; Deckert *et al.*, 2007). The *grand plié*, a deep knee bend, has been identified as a controversial movement (Berardi, 2005) as it has been suggested that it may be hazardous due to its extreme degree of knee flexion, large patellofemoral forces and excessive knee joint longitudinal rotation (Clippinger-Robertson *et al.*, 1985). In their investigation of the lower limb muscle activity associated with the *grand plié*, Trepman *et al.* (1998) reported that EMG activity of the vastus lateralis and vastus medialis was significantly less in ballet dancers than in modern dancers, despite similar degrees of knee flexion. Trepman *et al.* (1998) therefore reported that due to their constant repetition of the *grande plié,* ballet dancers may have lower patellofemoral joint reaction force than modern dancers, and the movement therefore may not necessarily be as potentially injurious as suggested.

Barnes *et al.* (2000) used 2D digitised video data to calculate external longitudinal rotation (ELR) of the knee joint during the *grand plié*. Their results indicated that ELR values were highest at the deepest part of the *plié*, the point of greatest knee flexion, in all of the five positions of the feet, with the ELR being greater in the 3rd and 4th positions, compared to 2nd position. On the basis of this research, Barnes *et al.* (2000) suggested that dance educators should exercise caution in including the *grand plié* in the training process. Krasnow and Chatfield (1997) investigated the 'alignment' of the torso during the *grande plié* and Deckert *et al.* (2007) looked at pelvic anterior/posterior 'placement' during the *grande plié* and *demi plié*. Gamboian *et al.* (1999; 2000), Couillandre *et al.* (2008) and Holt *et al.* (2011) were also interested in the anterior/posterior 'placement' of the pelvis during the *demi plié*. These studies reported that specific training programs can significantly affect torso 'alignment' (Krasnow and Chatfield, 1997) and pelvic 'placement' (Gamboian *et al.*, 1999; Gamboian *et al.*, 2000; Deckert *et al.*, 2007; Couillandre *et al.*, 2008; Holt *et al.*, 2011).

Biomechanical analysis of the rise (*relevé*) in classical ballet has also received some attention in the academic literature. The *relevé* in classical ballet is a movement in which the dancer raises themselves up to stand on the balls of the feet (*demi-pointe*) or all the way up onto the tips of the toes through use of specially constructed *pointe* shoes (*full point or "sur les pointe"*) (Grant, 2008). Nine studies on the *relevé* in classical ballet were identified. Five of these studied the biomechanics of the *relevé* to *demi pointe* (Chatfield, 1993; Gamboian *et al.*, 1999; Gamboian *et al.*, 2000; Masso *et al.*, 2004; Holt *et al.*, 2011) and four investigated the *relevé* to *full pointe* (Teitz *et al.*, 1985; Albers *et al.*, 1992; Dozzi and Winter, 1993; Lin *et al.*, 2005). Chatfield (1993) and Masso *et al.* (2004) both collected EMG data of dancers performing *relevés* in an effort to assess their motor control strategies. Masso *et al.* (2004) examined the activity of the peroneus longus, soleus, gastrocnemius, and abductor hallucis muscles in a balletic rise (*relevé* to *demi pointe* in *first position),* compared with a rise in a non-balletic (parallel) position of the feet. Results indicated decreased abductor hallucis muscle activity in the balletic position, which the authors suggested may be reflective of deficient stability of the internal arch and first ray, thereby leading to increased risk of injury. Gamboian *et al.* (1999; 2000) and Holt *et al.* (2011) studied the effects of particular training programs (somatic training; remote cueing) on pelvic anterior/posterior 'placement' during *relevé* to *demi pointe*. Both studies reported "improved" pelvic 'placement' as a result of the training programs. In relation to the studies on *relevés en pointe,* as mentioned in Section 2.2.3 the levels of pressure and force that dancers' feet are subjected to when dancing *pointe* has been an area of interest for a few researchers (Teitz *et al.*, 1985; Albers *et al.*, 1992; Dozzi and Winter, 1993). Teitz *et al.* (1985) measured the peak pressure on the first and second toes during *relevé en pointe* in *first position*, and Albers *et al.* (1992) measured the peak plantar pressure when performing a single leg (*relevé retiré*) or double leg (*relevé en first position*) *relevé en pointe.* Dozzi and Winter (1993) and Lin *et al.* (2005) calculated the joint reaction forces and torques/moments at the ankle joint for the *relevé en pointe.* Interestingly, Lin *et al.* (2005) reported that despite high correlations in bilateral comparisons of ankle joint plantar/dorsiflexion angles, only moderate correlations were found between the left and right sides in joint reaction torques/moments. The authors suggested that the two ankle joints may therefore play different roles in controlling balance and movement.

Classical ballet turns (*pirouettes*) have also been studied using quantitative biomechanical techniques. A *pirouette* is a spinning action of the entire body during which the dancer rotates with their body weight supported on a single leg. Nine published journal articles on the biomechanics of the classical ballet *pirouette* have been identified. The earliest of these studies were conducted by the research group of Laws and colleagues. These authors described the whole body angular momentum (Laws, 1979; Laws, 1998), and whole body angular displacement and velocity (Laws, 1986; Laws and Fulkerson, 1992) of classical ballet *pirouettes.* Golomer and colleagues (2008; 2009a; 2009b) presented data on the relative movements of the shoulder and hips and supporting leg displacements during whole body rotations (Golomer *et al.*, 2009b), and then went on to examine how whole body rotations can be affected by mental imagery styles (Golomer *et al.*, 2008) and vision and motor imagery (Golomer *et al.*, 2009a). Also very recently, Imura and colleagues described the angular momentum of the shoulder, arm, hip, and leg (Imura *et al.*, 2008), and the moment/torque of the supporting leg with respect to the friction coefficient of the floor (Imura *et al.*, 2010), during the *fouette* turn.

The biomechanical characteristics of jumping (*sauté*) and darting (*elancé*) movements in classical ballet have also been investigated. Four of the six studies that analysed ballet jumps used a force plate to obtain quantitative data (Poggini *et al.*, 1997; Laws and Petrie, 1999; Dworak, 2005; Chockley, 2008). Poggini (1997) compared the centre of gravity height for *sautés in first position* before and after implementation of a “physio-technique” training program. This author also compared jump elevation when jumping with “turned out” legs and with legs in a “natural” position. Most of the participants achieved a higher jump using a “natural” rather than a “turned out” position of the legs. Laws and Petrie (1999), and Chockley (2008) measured the ground reaction forces (GRF) associated with the *sautés in first position.* Laws and Petrie (1999) assessed the influence of arm position on GRF during take-off and on jump height. GRF was higher and jump elevation increased when subjects raised their arms over their head during take-off, compared to using a static arm position. Chockley (2008) examined the vertical jumps of ballet dancers landing *en pointe* and landing on the full foot, landing *en pointe* only required 72% of the GRF that landing on the full foot required. Dworak (2005) measured and compared the GRF during landing from a selection of standard ballet jumps (*grand pas de chat, grand pas assemblé, entrelacé, sauté basque, double tour),* GRF was greatest when landing from the *grand pas de chat.*

With respect to quantitative analysis of darting (*elancé*) movements in ballet, seven articles were located, each of these investigated the *grand jeté* (split leap). Hinson *et al.* (1978) described the segment and joint angles of the torso and lower limb during the *grand jeté en tournant entrelacé* (turning split leap), and the other six authors (Laws and Lee, 1989; Miller *et al.*, 1990; Midgett, 1993; Rasmussen and Hay, 1993; Shan, 2005; Kulig *et al.,* 2011) investigated the *grand jeté en avant* (forward split leap). Most of these authors (Laws and Lee, 1989; Midgett, 1993; Rasmussen and Hay, 1993) reported on the trajectory of the whole body centre of gravity during the airborne phase of the movement, and Miller *et al.* (1990) and Kulig *et al.* (2011) measured the GRF associated with landing from the *grand jeté*. In addition to GRF, Miller *et al.* (1990) also measured plantar pressure at the first and second toes, the first and second metatarsal heads, the medial and lateral arches, and heel while wearing different types of dance shoes. Results indicated that the GRF was not affected by shoe type, but the modifications in shoe design resulted in a more even distribution of pressure over the medial arch, away from the toes, metatarsal heads and heel. Kulig *et al.* (2011) analysed knee joint mechanics as well as GRF for the landing and take-off of the *grand jeté en avant.* Knee joint angles and torques/moments were calculated, and it was reported that landing was accomplished with less knee angular stiffness than take-off, despite greater peak GRF, and therefore landing from the *jeté* was considered to be more injurious to the knee soft tissue than take-off. Shan (2005) measured the hip, knee and ankle joint angles and estimated muscle lengths (biceps femoris, adductor magnus, gracillis, semimembranosus) for ballet dancers and tae kwon do martial artists performing the *grand jeté en avant*. Results showed that the most over lengthened muscle was the small adductor magnus muscle, and it was therefore suggested that small muscles are more likely to be injured in repetitive motion.

The stretch (*battement*) movement in classical ballet has also been analysed through quantitative means. Five journal articles on the *battement* were identified in the published literature. This list included the earliest identified quantitative study on the biomechanics of classical ballet technique (Ryman and Ranney, 1979) and two of the most recent studies (Bronner and Ojofeitimi, 2011; Holt *et al.*, 2011). Most of these studies (Ryman and Ranney, 1979; Deckert *et al.*, 2007; Bronner and Ojofeitimi, 2011; Holt *et al.*, 2011) were interested in analysing pelvic movement during the *battement* movement. As mentioned in Section 2.1.3.2, pelvic 'placement' was identified as one of the fundamental principles of classical ballet technique. Specifically, correct pelvic 'placement' involves minimal movement or disturbance of the pelvis from its centred or neutral position when raising the leg to the front, side, or back of the body. Deckert *et al.* (2007) and Holt *et al.* (2011) reported on the effects of individualised training approaches on sagittal plane pelvic placement for the *battement*. Both these studies used 2D video and digitisation techniques, and both reported that anterior pelvic tilt decreased after individual tutoring for durations of 3 weeks and 8 weeks, respectively. Ryman and Ranney (1979) and Bronner and Ojofeitimi (2011) compared the relative positions of the pelvis and thigh segments during execution of the *grand battement*. Ryman and Ranney (1979) used 2D techniques (cinecamera and tracings) and only examined the *grand battement devant* (front kick), while Bronner and Ojofeitimi (2011) used 3D computerised motion analysis and examined the *grand battement* to the front, side and back of the body. Despite the traditional manuals stressing that the working leg alone accomplishes the kick, and pelvic and spinal movements must be kept to a minimum for aesthetic reason (Ryman and Ranney, 1979), both studies reported that there is actually significant involvement of the pelvis during the *grand battement devant*. Ryman and Ranney (1979) concluded that as the leg is kicked to the front, the pelvis goes into increased posterior tilt, causing the lumbar curve to flatten. Bronner and Ojofeitimi (2011) also reported that in the *battement devant*, posterior pelvic tilt occurs, and that this exceeded the degree of posterior pelvic tilt during *grand battement* to the side. Pelvic obliquity toward the stance limb was also demonstrated during the *battement* in each direction, as was transverse plane pelvic rotation (Bronner and Ojofeitimi, 2011). The *grand battement* has also been examined though EMG analysis (Ryman and Ranney, 1979; Chatfield, 1993). Such EMG data has illustrated considerable variations in patterns of muscle activity, despite similarities in dancer training and kinematic execution of the movement (Ryman and Ranney, 1979).

The last of Noverre's 'Seven Movements of Dance' (1760) that has not yet been discussed is the glide (*glissé*) movement category. It was not possible to identify any published journal articles that used quantitative biomechanics technique to analyse the *glissé*, this movement category will therefore not be discussed any further in this literature review.

Although not included in Noverre's 'Seven Movements of Dance', another movement type that has received some attention in the academic literature, and that is often performed in classical ballet repetoire, is the "lift". Lifts in classical ballet typical involve a male dancer lifting a female dancer off the floor and supporting her entire body weight in various positions against his body or above his head. Alderson *et al.* (2009) used 3D motion analysis to measure lumbar extension velocity, horizontal hand to feet distance, and to estimate the forces generated at the L5/S1 joint in professional and pre-professional male dancers performing two different lifts (*full pressage lift; arabesque lift*). Ground reaction force data were also presented. Interestingly, the estimated peak lumbar anterior shear force was found to occur at the beginning of each lift, approximately 0.01 seconds prior to the ballerina moving vertically into the lift. The compression forces were found to be greater than the National Institute of Occupational Safety and Health, Back Compression Design Limit (3400N), suggesting a requirement for administrative controls to be placed on the number of lifts performed by male dancers daily, in order to reduce the risk of lower back injury (Alderson *et al.*, 2009).

In consideration of Noverre's 'Seven Movements of Dance' (1760), review of the published literature reveals that the majority (87%) of studies that have conducted a quantitative analysis of classical ballet movement have analysed the biomechanical characteristics of only a single step or single movement category. Only a few studies have attempted to examine more than one movement category. For example, some researchers have analysed two of the seven movements, such as the bend (*plié*) and rise (*relevé*) (Gamboian *et al.*, 1999; Gamboian *et al.*, 2000; Holt *et al.*, 2011), bend (*plié*) and stretch (*battement)* (Deckert *et al.*, 2007), or bend (*plié)* and jump (*sauté)* (Couillandre *et al.*, 2008). Only two studies (Chatfield, 1993; Holt *et al.*, 2011) attempted to assess steps from more than two movement categories. Holt *et al.* (2011) measured pelvic tilt for the bend (*plié*), rise (*relevé*), and stretch (*battement*); and Chatfield (1993) presented EMG data for steps from the bend (*plié*), rise (*relevé*), stretch (*battement*), and jump (*sauté*) movement categories. No published studies were identified that analysed the biomechanical characteristics of all seven movement categories.

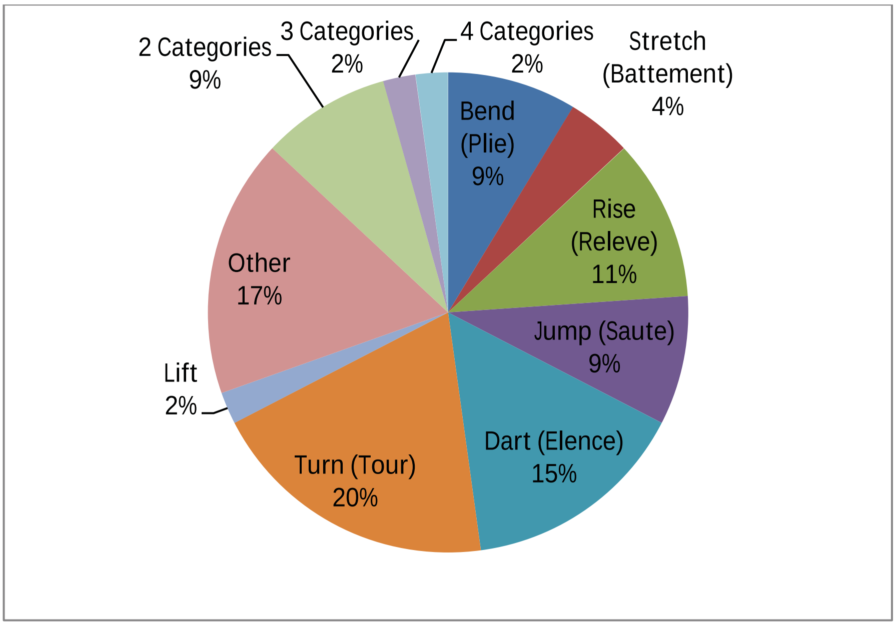


Figure 2.24 *Summary of dance movement categories analysed in quantitative ballet biomechanics research*

2.2.5.3 <u>Quantitative Biomechanical Analysis of the Fundamental Principles of Classical Ballet</u>

In Section 2.1.3, four fundamental principles of classical ballet technique were identified and described. These were defined as 'alignment', 'placement', 'turnout', and 'extension'. The biomechanical analyses that will be conducted as part of the current research project will involve assessment of classical ballet movements in relation to these four principles. It is interesting therefore to consider how, or indeed if, the existing research on the biomechanics of classical ballet technique relates to these principles.

The review of the literature indicates that while it is possible to relate some of the existing research to the four fundamental principles, the majority (52%) of the quantitative biomechanics studies on classical ballet technique cannot easily be associated with one of these fundamental principles. This is largely due to the fact that most of these studies collected and presented data types other than kinematic data. For example, joint reaction torques/moments (Kwon *et al.*, 2007; Imura *et al.*, 2008; Imura *et al.*, 2010; Kulig *et al.*, 2011), ground reaction forces (Miller *et al.*, 1990; Laws and Petrie, 1999; Dworak, 2005; Chockley, 2008; Kulig *et al.*, 2011), EMG data (Chatfield, 1993; Wilmerding *et al.*, 2001; Couillandre *et al.*, 2008) and pressure data (Teitz *et al.*, 1985; Miller *et al.*, 1990; Albers *et al.*, 1992) have provided interesting and useful information to assist in understanding some of the biomechanical aspects of ballet steps, however these data types do not reveal any detail about the resulting movement pattern displayed by the dancer, *i.e.* the visually perceivable elements of the movement. Other studies that did report kinematic data, but that still could not be easily related to the four fundamental principles of ballet technique, were mostly concerned with whole body angular momentum (Laws, 1979), angular displacement (Laws, 1986; Laws and Fulkerson, 1992), angular velocity (Laws, 1986), and linear centre of mass displacement (Laws and Lee, 1989; Midgett, 1993; Rasmussen and Hay, 1993; Poggini *et al.*, 1997), rather than inter-segmental interactions.

Amongst those studies that could be linked with one or more of the four fundamental principles of classical ballet technique, kinematic characteristics related to 'alignment' and 'placement' have received the most attention. Nine studies were identified that reported kinematic variables relating to the principle of 'alignment'. In one of the earlier studies, Woodhull-McNeal (1990) assessed the "linearity" of dancers' posture by measuring the horizontal distances of bony land marks (ear, shoulder, hip, knee, ankle) from the line of the centre of the gravity. In a similar study, Krasnow and Chatfield (1997) calculated the horizontal anterior-posterior displacement of ear, shoulder and greater trochanter markers from the foot marker to obtain a measure of "vertical central alignment". Trepman and colleagues (1994; 1998) measured anterior-posterior body sway; and lumbar flexion/extension was analysed by Gamboian's research group (1999; 2000), Feipel *et al.* (2004), Wilson *et al.* (2004) and Alderson *et al.* (2009).

With respect to the principle of 'placement', orientation of the pelvic segment is the kinematic variable of relevance. Of the 10 studies whose results can be related to 'placement', those that used 2D kinematic techniques presented only sagittal plane pelvic tilt data (Ryman and Ranney, 1979; Gamboian *et al.*, 1999; Gamboian *et al.*, 2000; Deckert *et al.*, 2007; Holt *et al.*, 2011), while those that used 3D techniques were also able to present coronal plane pelvic data (Wilson *et al.*, 2004; Wilson *et al.*, 2007; Bronner and Ojofeitimi, 2011), and/or transverse plane pelvic data (Golomer *et al.*, 2008; Golomer *et al.*, 2009b; Bronner and Ojofeitimi, 2011). Some of these studies investigated the 'placement' of the pelvis in relation to thigh segment movement (Ryman and Ranney, 1979; Wilson *et al.*, 2004; Wilson *et al.*, 2007; Bronner and Ojofeitimi, 2011), or thoracic segment movement (Golomer *et al.*, 2008; Golomer *et al.*, 2009b), while others looked at pelvic placement in isolation from the movements of other segments (Gamboian *et al.*, 1999; Gamboian *et al.*, 2000; Deckert *et al.*, 2007; Holt *et al.*, 2011).

The results of quantitative research on classical ballet can also be related to the principle of 'extension'. This principle is concerned with the elongation of the lower limb (*i.e.* maximum knee extension and maximum ankle plantarflexion). Hinson *et al.* (1978) reported that the knees and ankles were "well extended" during the airborne phase of a *tour jeté* (turning leap), and Shan (2005) measured knee and ankle angles during a *grand jeté en avant* (forward leap). Lin *et al.* (2005) and Dozzi and Winter (1993) calculated ankle plantarflexion angles during the *relevé en pointe* in *first* and *second* positions respectively, and Masso *et al.* (2004) reported ankle plantarflexion angles for the *relevé* to *demi-pointe* in *first* position.

Classical ballet requires maximum external rotation, "turnout", of the lower limb joints. Interestingly, despite the fact that "turnout" is such a crucial element of classical ballet technique, there is relatively little published quantitative research, involving instrumented biomechanical analysis, that can be related to this principle. Only a few studies were identified that had some relevance to "turnout". Barnes *et al.* (2000) measured longitudinal rotation (ELR) of the knee joint during the *grand plié* (deep knee bend). The relatively high ELR measured at the base of the *grand plié* was suggested to be indicative of an increased injury risk of repetitive performance of the *grand plié* (Barnes *et al.*, 2000). In relation to hip rotation, Shan (2005), Wilson *et al.* (2007) and Bronner and

Ojofeitimi (2011) all used 3D motion analysis to measure hip rotation during the *grand jeté en avants*, the *grand rond de jambe en lair en dehors*, and the *grand battement*, respectively.

2.2.5.4 Subjects Included in Quantitative Biomechanical Analysis of Ballet

The numbers and types of subjects recruited for biomechanical assessment of ballet technique is another interesting point to consider. Review of the literature indicates that the majority (80%) of studies have recruited only one group of subjects. The number of subjects recruited into a single group has ranged from 1 participant (*i.e.* a case study) up to 61 participants. The mean number of participants across all 37 studies that analysed only one group of subjects was 10, while the most frequently occurring number of participants recruited to a single group was 1. Figure 2.25 depicts the subject group sizes for single group quantitative ballet studies. As displayed in the graph, the majority of single group studies had less than 16 subjects recruited to the group.

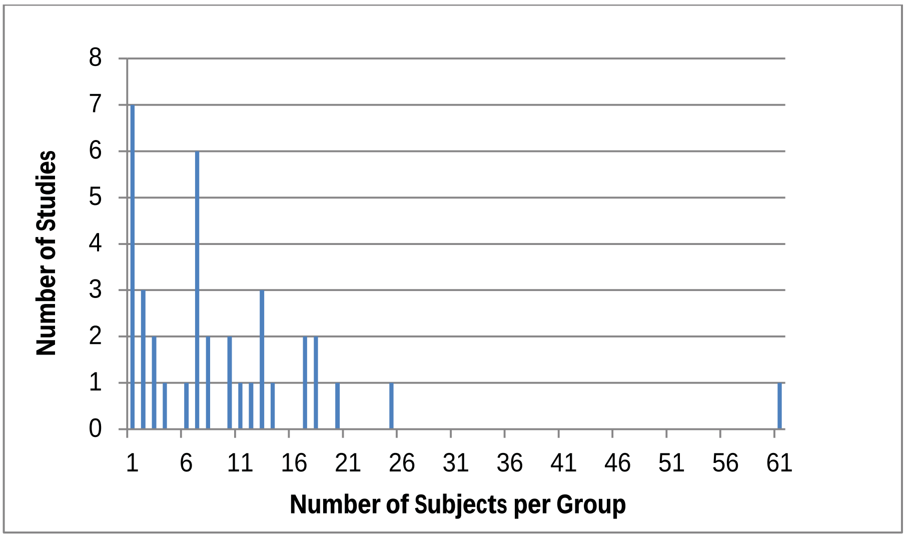


Figure 2.25 *Sample size for single group studies involving quantitative instrumented biomechanical analysis of classical ballet technique*

With respect to the selection criteria used for recruitment of dancers to the single group studies, most studies (40%) have been interested in analysing the biomechanical characteristics of professional ballet dancers, while some (24%) recruited elite pre-professional ballet dancers. Eight studies (23%) described their subjects as dance students, categorised under various headings, *e.g.* “advanced” (Teitz *et al.*, 1985;

Rasmussen and Hay, 1993) and "highly trained" (Shan, 2005), or according to a specific number of years of training (Woodhull-McNeal *et al.*, 1990; Albers *et al.*, 1992; Poggini *et al.*, 1997; Lin *et al.*, 2005; Imura *et al.*, 2008; Imura *et al.*, 2010). Seven studies (19%) recruited university or college dancers with varying levels of training (Chatfield, 1993; Midgett, 1993; Krasnow and Chatfield, 1997; Gamboian *et al.*, 1999; Gamboian *et al.*, 2000; Chockley, 2008; Bronner and Ojofeitimi, 2011), and the remaining studies (Laws and Lee, 1989; Laws and Petrie, 1999) did not provide any indication of the level of training of the recruited dancers.

Some research studies have compared biomechanical parameters between different groups of dancers performing classical ballet steps. Comparisons have been made between professional dancers of different genres, *e.g.* professional ballet dancers versus professional modern dancers (Trepman *et al.*, 1994; Trepman *et al.*, 1998); or between professional ballet dancers and practitioners of other movement disciplines, such as tai kwon do (Shan, 2005). One study was interested in the differences in lower limb kinematic patterns between males and females in their execution of classical ballet movements (Bronner and Ojofeitimi, 2006), while others have investigated biomechanical differences between groups in relation to their level of dance training (Wilson *et al.*, 2004; Kwon *et al.*, 2007; Golomer *et al.*, 2008; Golomer *et al.*, 2009b). Wilson *et al.* (2004) and Kwon *et al.* (2007) looked at the differences between skilled and novice college dancers in lower limb kinematics and kinetics, respectively. Golomer and colleagues (2008; 2009b) analysed and compared supporting leg displacements and relative positions of the shoulders and hips, in expert ballet dancers and untrained dancers in their execution of a single leg spin (*pirouette*). Dancers have also been recruited to quantitative studies on ballet biomechanics based on the type of treatment they have received for injury. Bronner *et al.* (2002) investigated the effects of the type of graft selected for anterior cruciate ligament (ACL) reconstruction on lower limb biomechanics. Hip and knee joint displacements and velocities for subjects who had received a semitendinosus - gracilis graft were compared with those who had received a patella tendon - bone graft. The movement patterns of both groups were compared with skill-matched controls. Although dancers with ACL reconstruction had returned to full dancing and performance at the time of analysis, results showed that kinematic differences still existed in both the involved and uninvolved lower limbs of those with ACL reconstruction compared to controls.

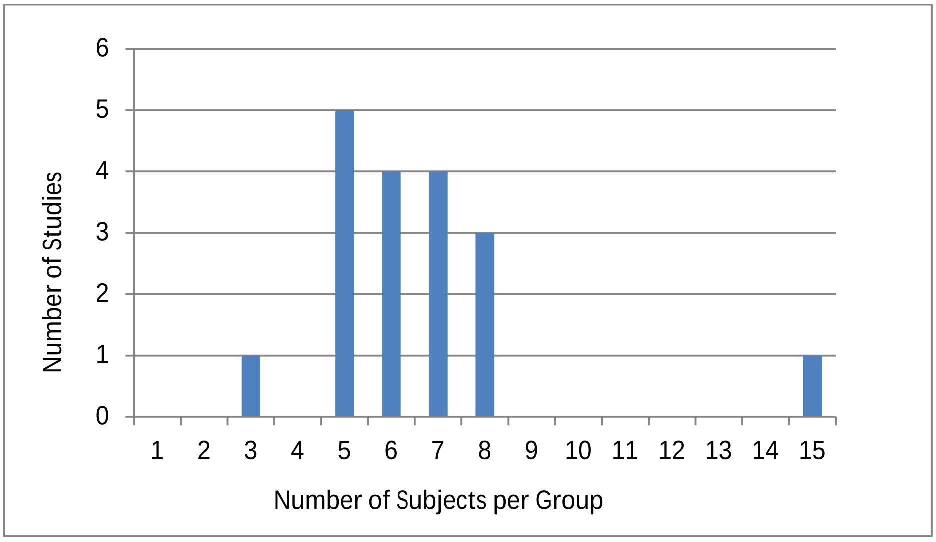


Figure 2.26 *Sample size for multiple group studies involving quantitative instrumented biomechanical analysis of classical ballet technique*

The numbers of subjects recruited to each group in the inter-group comparison studies has ranged from groups of 3 up to groups of 15. The mean and standard deviation of the number of subjects per group, across the 9 multiple group studies indentified, was 6.6 and 2.5, respectively. As indicated in Figure 2.26, most inter-group comparison studies had group sizes of between 5 and 8 subjects.

2.2.5.5 Three-dimensional Motion Analysis of Classical Ballet Technique.

Since the methodology of this thesis will include 3D motion analysis of classical ballet movements, the research involving 3D motion analysis of classical ballet technique will be reviewed in more detail. Only 11 such journal articles were identified, and Table 2.1 provides a summary of each of the different aspects of these studies.

Author	Year	Study Purpose	Movement Category	Subjects	Kinematic Variables Measured	Relevant Ballet Principle
Masso *et al.*	2004	Movement description	*Relevé*	Professional ballet dancers (N=18)	Ankle plantar-flexion	Extension
Wilson *et al.*	2004	Movement description	*Other*	Skilled college dancers (N=5), Novice college dancers (N=5)	Trunk & pelvis global angles	Alignment Placement
Shan	2005	Injury link	*Elancé*	Highly trained ballet dancers (N=6), Highly trained Tai Kwon Do artists (N=5)	Hip, knee & ankle 3D joint ROM	Extension Turnout
Lin *et al.*	2005	Movement description	*Relevé*	Dancers with over 5 years dance training and over 3 years *pointe* experience (N=13)	Ankle plantar-flexion	Extension
Wilson *et al.*	2007	Movement description	*Other*	Experienced female ballet dancers (N=8)	Pelvis global angles, hip 3D angles of "working" leg	Placement Turnout
Golomer *et al.*	2008	Motor control	*Tour*	Professional ballet dancers (N=8), Untrained controls (N=7)	Horizontal shoulder-pelvis angles; Supporting leg displacements	Placement
Alderson *et al.*	2009	Injury link	*Other - Lift*	Professional and pre-professional male ballet dancers (N=8)	Trunk flexion, lateral flexion and rotation	n/a
Golomer *et al.*	2009a	Motor control	*Tour*	Professional ballet dancers (N=10)	Supporting foot displacement	n/a
Golomer *et al.*	2009b	Motor control	*Tour*	Professional ballet dancers (N=8), Untrained controls (N=7)	Horizontal shoulder- pelvis angles; Supporting leg displacements	Placement
Kulig *et al.*	2011	Injury link	*Elancé*	Elite pre-professional dancers (N=12)	Knee flexion	n/a
Bronner & Ojofeitimi	2011	Movement description	*Battement*	Advanced college dancers (N=17)	Pelvis and hip angles	Placement Turnout

***Table 2.1** Summary of quantitative biomechanics research studies that used 3D motion analysis and reported kinematic data.*

As has been previously mentioned, the methodology used for kinematic biomechanical analysis closely reflects the year of publication, and as such, all of the studies that have used 3D techniques to assess classical ballet technique have been published since 2004. In terms of the purpose or aim of these studies, most aimed to provide a 'biomechanical description' of the movements (Wilson *et al.*, 2004; Masso *et al.*, 2004; Lin *et al.*, 2005; Wilson *et al.*, 2007; Bronner and Ojofeitimi, 2011), however work by Golomer and colleagues (2008; 2009a; 2009b) focused on 'motor control', while Shan (2005), Alderson *et al.* (2009) and Kulig *et al.* (2011) investigated ways in which classical ballet movements may be associated with injury. None of the 3D motion analysis studies looked at the effects of training programs or dance shoes or surfaces on classical ballet technique.

The most commonly analysed movement category was the turn (*tour*), (Golomer *et al.*, 2008; Golomer *et al.*, 2009a; Golomer *et al.*, 2009b), followed by the rise (*relevé*) (Masso *et al.*, 2004; Lin *et al.*, 2005) and dart (*elancé*) (Shan, 2005; Kulig *et al.*, 2011). Only one study (Bronner and Ojofeitimi, 2011) used 3D motion analysis to analyse the stretch (*battement*), and the bend (*plié*), jump (s*auté*), and glide (*glissé*) have not been examined in any published studies involving 3D motion analysis of ballet technique. No study attempted to analyse more than one of the 'Seven Movements of Dance' (Noverre 1760).

With respect to subjects, nearly half of the studies (Masso *et al.*, 2004; Golomer *et al.*, 2008; Golomer *et al.*, 2009a; Golomer *et al.*, 2009b; Alderson *et al.*, 2009) recruited professional ballet dancers, while other studies described their participants as "novice" (Wilson *et al.*, 2004), "skilled" (Wilson *et al.*, 2004) or "advanced" (Bronner and Ojofeitimi, 2011) college dancers. Shan (2005) described recruited subjects as being "highly trained", without reference to the dancers being college students, professional dancers, or having any other such affiliation. Some studies compared kinematic variables between different groups of dancers (Wilson *et al.*, 2004); between dancers and martial artists (Shan, 2005); or between dancers and untrained controls (Golomer *et al.*, 2008; Golomer *et al.*, 2009b); however most studies analysed data for only a single group of dancers (Masso *et al.*, 2004; Lin *et al.*, 2005; Wilson *et al.*, 2004; Alderson *et al.*, 2009; Golomer *et al.*, 2009a; Kulig *et al.*, 2011; Bronner and Ojofeitimi, 2011). Across all 11 studies that used 3D motion analysis for analysis of ballet technique, the mean and standard deviation for the number of participants per group was 9.1 and 4.1, respectively.

'Placement' was the fundamental principle of classical ballet technique that most studies could be related to (Wilson *et al.*, 2004; Wilson *et al.*, 2007; Golomer *et al.*, 2008; Golomer *et al.*, 2009b; Bronner and Ojofeitimi, 2011). 'Turnout' (Shan, 2005; Wilson *et al.*, 2007; Bronner and Ojofeitimi, 2011) and 'extension' (Masso *et al.*, 2004; Lin *et al.*, 2005; Shan, 2005) have each been discussed in three studies, while data relating to 'alignment' has only been reported in one study (Wilson *et al.*, 2004). Also with respect to the four fundamental principles, most single studies could only be linked with one (Masso *et al.*, 2004; Lin *et al.*, 2005; Golomer *et al.*, 2009a; Golomer *et al.*, 2009b) or two (Wilson *et al.*, 2004; Shan, 2005; Wilson *et al.*, 2007; Bronner and Ojofeitimi, 2011) of the fundamental principles.

In completing this section of the literature review, it has become clear that interest in the field of quantitative dance biomechanics has increased in recent years. Forty percent (40%) of the quantitative research identified in this review has been produced during the past six years, with all of the 3D motion analysis research being conducted during this time. The studies that have been published to date have had a variety of aims and have analysed a few different dance genres, however classical ballet has been the most commonly researched area. With respect to the studies that have investigated classical ballet technique, what is of extreme relevance to the current research thesis is the fact that only 11 published studies have used 3D motion analysis to report kinematic data. Of even more importance, is the finding that amongst these 11 studies, no single published study has used 3D motion analysis to analyse classical ballet technique in terms of a set of fundamental biomechanical principles of the technique, nor in terms of all 'Seven Movements of Dance', as described by Noverre (1760). For this reason, the aims and methodologies proposed in the current research thesis are unique amongst existing literature, and as such it is anticipated that this thesis will make a distinct and original contribution, not only to the field of dance science research, but also to the broader area of quantitative analysis of human movement.

2.3 Qualitative Analysis of Human Movement

2.3.1. Introduction

The ability to accurately and reliably observe movement patterns is a key factor in all fields endeavouring to enhance and alter human movement. Dance teachers and sports coaches work to assist their students to become highly skilled in their chosen discipline, integral to which is observing their students' movement patterns and providing immediate useful and effective feedback. Often this process must happen over durations as short as a fraction of a second (McPherson, 1996). This process is not limited to instruction of skilled or expert movement. In clinical practice, visual observation of human movement is often used to identify movement disorders in activities of daily living, and to evaluate treatment or intervention outcomes. It is a skill used by physiotherapists to improve the movement abilities of patients undergoing physical rehabilitation, and to estimate work postures and movements in the fields of ergonomics and occupational health and safety. This process of visually analysing human movement has been labelled as "qualitative analysis" and has been defined as the "systematic observation and introspective judgment of the quality of human movement for the purpose of providing the most appropriate intervention to improve performance" (Knudson and Morrison, 1997, p4). "Qualitative analysis" is a complex process that instructors must be able to employ using their innate perceptual abilities, combined with their knowledge of the skill or movement discipline being instructed. Thus, most sports coaches, dance teachers, clinicians and ergonomists regularly use qualitative analysis in their everyday practice to diagnose and correct movement errors.

The accuracy and reliability of qualitative movement analysis is vitally important to the teaching and learning of physical skills. Accurate qualitative analysis helps students to improve their motor skills and gain confidence in the analyst and themselves. Inaccurate or inconsistent qualitative analysis however, can just as easily lead to frustration and poor performance (Knudson, 2000). In clinical practice, in ergonomics and in some sporting disciplines, specific tools have been developed to help ensure that qualitative analysis is conducted with as much reliability and accuracy as possible. The following sections will firstly outline some of the tools typically used in the application of qualitative analysis of human movement, and will then define the terms reliability and accuracy in relation to movement assessment. Lastly a review of the academic literature that has investigated the accuracy of qualitative analysis of human movement in clinical practice, in occupational health and safety, and in various sporting disciplines will be presented.

2.3.2 Application of Qualitative Analysis of Human Movement

2.3.2.1 Qualitative Analysis of Human Movement in Clinical Practice

Gait analysis constitutes a major aspect of physiotherapy practice and is frequently employed to assess patients' movement abilities. Due to the ease of use of visual gait analysis compared to 3D computerised gait analysis, many clinicians routinely rely on this method to assess their patients. Over the past few decades, a number of observational gait assessment tools have been developed for use in clinical practice. The assessment tools usually consist of rating scales for numerous gait parameters for which abnormalities commonly exist in pathological populations. A few observational gait analysis scales have been developed for general analysis of all clinical populations (Winter, 1985; Perry, 1992), however the need for more population-specific scales has led to the development of various visual gait assessment scales specific to particular clinical populations. Scales have been developed for patients with lower limb amputation (Saleh and Murdoch, 1985) rheumatoid arthritis (Eastlack *et al.*, 1991), podiatry patients (Keenan and Bach, 1996), hemiplegia following stroke (Goodkin and Diller, 1973; Miyazaki and Kubota, 1984; Hughes and Bell, 1994; Lord *et al.*, 1998; McGinley *et al.*, 2003; Watelain *et al.*, 2005; McGinley *et al.*, 2006), orthopaedic disorders (Brunnekreef *et al.*, 2005), and for cerebral palsy (Corry *et al.*, 1998; Krebs *et al.*, 1985; Koman *et al.*, 1994; Boyd and Graham, 1999; Dickens and Smith, 2006; Kawamura *et al.*, 2007; Read *et al.*, 2003; Piripis *et al.*, 2001; Flett *et al.*, 1999).

When using observational gait analysis tools observers are typically required to estimate joint angles at particular phases or points in the gait cycle. The joint angles are often expressed in terms of levels of deviation from "normal" gait. These estimations are made using a variety of techniques. In one of the earlier scales developed, the Waterloo Gait Profile Form (Winter, 1985), observers record their ratings by circling one of a selection of stick diagrams and/or symbols that they believe most closely represent the trunk, knee and foot movement patterns they observed. The Rancho Los Amigos System (Olsson, 1990; Perry, 1992) is based on a form that is laid out in a tick box format. The user identifies deviations from normal gait by ticking a box for the frontal, sagittal and transverse plane rotations at the trunk, pelvis, hip, knee, ankle and toes. Deviations from normal gait are categorised as minor or major, but no specific guidelines or joint angle ranges are provided to assist the user in establishing what constitutes ‘major’ or ‘minor’ deviation. The Rivermead Visual Gait Assessment (Lord *et al.*, 1998), a tool developed for assessment of neurologically impaired patients, comprises a 4-point scale (0 – 3) to grade joint or segment positions as either normal (0), mild (1), moderate (2), or severe (3), and where appropriate indicate the direction of deviation. However, as for the Rancho Los Amigos System, there is some ambiguity about the criteria for selection of each grade in this system. The Physician Rating Scale (Koman *et al.*, 1994) is a tool that is commonly used to assess the gait of children with cerebral palsy. It examines the knee, ankle and equinus foot in the sagittal plane, and uses either 3- or 4-point scales to identify deviations from normal. For example, the extent to which a patient exhibits ‘crouch’ gait (*i.e.* increased knee flexion) is recorded using a 4-point scale (*i.e.* severe (0), moderate (1), mild (2), or none (3)), however in this scale users are also presented with associated joint angle ranges to assist in selecting the appropriate grade or category.

Modified versions of the Physician’s Rating Scale (PRS) (Corry *et al.*, 1998; Flett *et al.*, 1999; Boyd and Graham, 1999; Mackey *et al.*, 2003; Wren *et al.*, 2005; Dickens and Smith, 2006; Brown *et al.*, 2008) have also been developed. These modified versions all still focus on knee, ankle and foot parameters, but alterations have been made to the number and type of ratings required for each joint. While most modified versions of the PRS provide joint angle ranges as well as references to normality, some other versions of the PRS (Wren *et al.*, 2005) provide joint angle ranges with no indication as to how the joint range categories relate to normal. In contrast, other newer scales (Kawamura *et al.*, 2007) have been developed in which raters are asked to assess joint movements in multiple planes only in terms of “normality”. For example, in Kawamura *et al.* (2007), observers are required to use a 3-point scale to record if the joint movement is “normal”, “decreased”, or “increased”. All the above mentioned gait scales are typically conducted using live visual observation, rather than video-based observation. However, there are some scales that have been designed specifically for video-based observation. A well known gait assessment tool typically conducted via video analysis, is the Edinburgh

Visual Gait Score (Read *et al.*, 2003). It requires raters to make observations of 17 different joint parameters for each lower limb of patients with cerebral palsy. Joint and segment angles for the trunk, pelvis, hip, knee and ankle are estimated using a 5-point scale, for which joint angle ranges and references to normality are provided. As suggested by the large number of parameters contained in the Edinburgh Visual Gait Score, use of video analysis allows for observations of more parameters than live observations, as the video can be replayed multiple times to obtain all the required information.

Observation of human movement in clinical practice is not limited to observational gait analysis. In the clinical setting therapists often use other functional performance tests based on visual observation to evaluate the movement abilities of patients (Harrison *et al.*, 1994; Bernhardt *et al.*, 1998; Haupstein and Goldie, 2000; Bernhardt *et al.*, 2002; Björklund *et al.*, 2006; von Porat *et al.*, 2008). The one-legged standing balance test (Harrison *et al.*, 1994; Haupstein and Goldie, 2000) is one protocol which is used frequently in the fields of neurology, paediatrics, geriatrics, orthopaedics and sports medicine. In this test subjects are asked to stand as still as possible over the narrow base of support provided by one foot, with eyes open or closed. Inferences are made about balance on the basis of how steadily this challenging posture can be held. Clinicians evaluate the movement strategy that the person uses to maintain balance to judge whether a rehabilitation program is required, or has been effective in correction of any observed deficiency in balance. Other functional performance tests used in clinical practice may involve evaluation of running, one- and two-legged squatting , sit-to-stand, distance hoping, cross-over hoping, and vertical jumping (Björklund *et al.*, 2006; von Porat *et al.*, 2008). Upper limb function (Bernhardt *et al.*, 1998; Bernhardt *et al.*, 2002), and head and neck posture (Youdas *et al.*, 1991; Passier *et al.*, 2010) are also often assessed by visual observation in clinical practice.

2.3.2.2 <u>Qualitative Analysis of Human Movement in Human Factors and Ergonomics</u>

Due to legal and other requirements, various methods have been developed for assessing exposure to risks linked with work-related musculoskeletal disorders, and for documenting changes in exposure associated with introducing workplace interventions. These include instrumentation-based techniques, subjective self reports and other psychophysiological and visual observational methods (Li and Buckle, 1999). It is presumed that the most accurate exposure data are obtained by instrumentation-based technical measurements (Genaidy *et al.*, 1993). However, as per 3D gait analysis, these techniques may be too expensive and time consuming when attempting to analyse large numbers of subjects. Thus, systematic visual observation applied by experienced ergonomists may offer a compromise. Observational techniques, specially developed for the evaluation of occupational activities, have therefore become popular as they are widely applicable, cost effective and often easy to use (Burdorf *et al.*, 1992). In general, almost all of the observation methods published to date concentrate on working postures, with some methods adding assessment of other factors such as force, duration, frequency, perceived exertion, or type of work activity. Most postural observation systems concentrate on assessment of the back, neck, shoulders and arms. This is understandable as the prevalence of work-related musculoskeletal problems of the lower extremity is not as frequently reported as those of the upper body segments (Li and Buckle, 1999). Some observational methods have been developed for use in specific industries, such as construction (OWAS), transportation (TRAC) or healthcare (REBA), while others have a more general use in various industries (HARBO).

Most workplace qualitative analysis methods are based upon repeated observations of the worker throughout either a number of representative work cycles or a specified period of time. Two general methodologies for visual observation techniques can be distinguished, (1) continuous recording of events as they occur in real time (*e.g.* PEO, TRAC, VIRA HARBO), and (2) time-sampled or intermittent observations in which data are collected at pre-specified time intervals (*e.g.* OWAS, RULA, PATH, ARBAN, 3DMatch). Continuous real time observations are typically used to assess work activities that can change rapidly and frequently and do not always follow a consistent pattern from one cycle to another. Continuous observations thus provide information about the sequence, duration and frequency of the observed postures, while time-sampled observations only provide an estimate of this information. In time-sampled observations, the percentage of time spent in a given posture is computed as the ratio of the number of observations recorded for this posture and the total number of observations (Genaidy *et al.*, 1994), therefore it is assumed that the higher the sampling frequency, the more accurate the time-based records obtained, however very few reports give any advice on appropriate sampling rates when using this method. Some observation tools such as ROTA (Ridd *et* *al.*, 1989), TRAC (van der Beek *et al.*, 1992), and RULA (McAtamney and Corlett, 1993) facilitate optional time sampling or continuous real time monitoring. It has been reported (Bao *et al.*, 2007) that there is poor agreement between RULA scores obtained with event-based (continuous observations) and time-based (intermittent observations) postural analysis methods. Therefore, postural analysis data based on one postural analysis method would not necessarily be equivalent to those generated by the other method.

In addition to the sampling strategy of observation, visual observation tools can also be categorised as being based on either 'macropostural' classifications or 'micropostural' classifications (Genaidy *et al.*, 1994). Macropostural classification systems group multi-planar non-neutral positions around a joint into one category. For example, in one of the earliest macropostural systems, the Ovako Working Postures Analysing System (OWAS), Karhu *et al.* (1977) classified the flexion, extension and lateral bending of the lower back as 'bending'. Arm movements are classified in the OWAS as elevation above or below the shoulder joint, with 'elevation' including flexion, extension, abduction and adduction. Heinsalmi (1986) expanded the OWAS system to include head positions around the neck for which postures were described as 'bending' and 'rotation'. The 'micropostural' classifications are more detailed than the 'macropostural' classification procedures (Genaidy *et al.*, 1994), and usually contain more than one category or level of non-neutral uni-planar joint posture. For example, Keyserling (1986) modelled lower back flexion into two levels; moderate flexion (16 - 45°) and severe flexion (>45°), and shoulder flexion has been classified into three categories (Kilbom *et al.*, 1986), and four categories (Armstrong *et al.*, 1982). Genaidy *et al.* (1993) and Armstrong *et al.* (1982) both modelled wrist flexion/extension into five angle categories.

2.3.2.3 Qualitative Analysis of Human Movement in Sports

Due to the huge variety of sports, and the vast array of tasks, aims, and measures of competency that are associated with each different sporting discipline, it is not feasible to review specific assessment scales that have been devised for individual sports. Instead, this review will briefly discuss some of the comprehensive models of qualitative analysis of skilled movement that have been proposed by renowned scholars in sports pedagogy

(Arend and Higgins, 1976; Hay and Reid, 1982; McPherson, 1990; Knudson and Morrison, 1997).

Arend and Higgins (1976) made a significant contribution to the study of qualitative analysis by presenting one of the first systematic methods for assessing skilled human movement performance. The system consisted of three major phases; (1) pre-observation, (2) observation, and (3) post-observation. Pre-observation involves multilevel breakdown or decomposition of the movement (Arend and Higgins, 1976) in order to obtain information about the prerequisites essential for successful performance of the skill. This includes identification of the "critical features" of the skill, as well as specific characteristics of the performer and their environment, in order to determine what it is that one "expects to see". "Critical features" were defined as "parts of the movement that could be least modified to be successful" (Arend and Higgins, 1976, p45). Some authors have since advocated that "critical features" be customised for the age or developmental level of the performer (Abendroth-Smith *et al.*, 1996). Secondly, in the observation phase it is necessary to make systematic observations over repeated trials with each trial used to view a particular aspect or phase of the movement, so that by the last trial a clear record of the entire performance has been obtained. This information should be clearly documented by answering a series of carefully devised questions.

Lastly, Arend and Higgins (1976) state that by utilising the information gained in the first two stages, comparisons and evaluations can be made during the post-observation phase, between what the observer expected to see happen and what actually happened. From this information feedback is provided to the performer. The Arend and Higgins (1976) model was very significant in the field of sports pedagogy as it was one of the first models to provide an integrated analysis of human movement incorporating aspects of biomechanics, pedagogy and motor development.

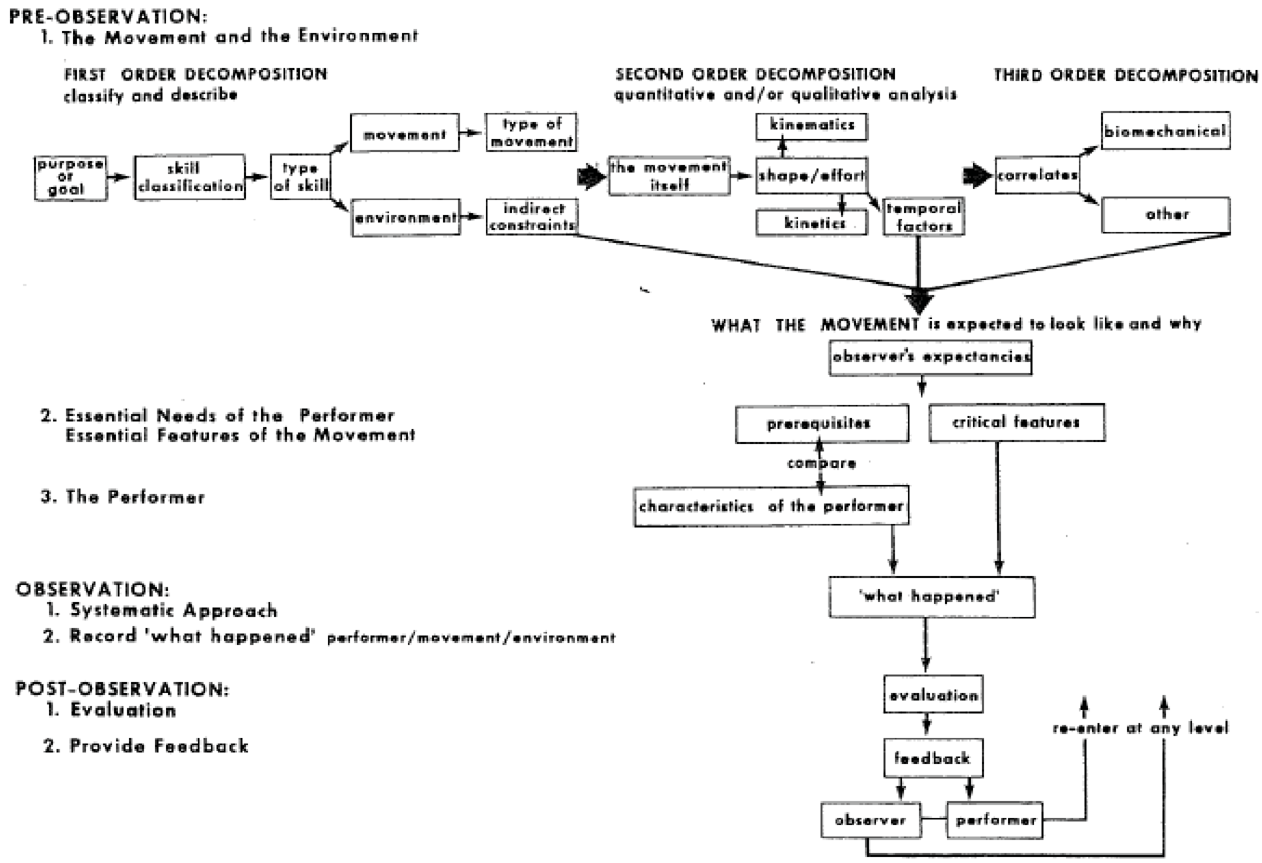


Figure 2.27 *A strategy for the qualitative analysis of human movement (from Arend and Higgins 1976, p38)*

Another widely cited model is the 'deterministic' model of qualitative analysis, first presented by Hay and Reid (1982). This model consists of four steps, (1) develop a model of the skill, (2) observe performance and identify faults, (3) rank the priority of faults, and (4) instruct the performer. The first task of developing a model of the skill requires the observer to identify the primary goal, result, or outcome of the skill to be investigated, and to identify those factors that produce this result. The outcome of a performance can be an objective measure (*e.g.* distance, height, time, etc), or a subjective measure (*e.g.* points awarded in gymnastics and diving competitions) (Chow and Knudson, 2011), and the factors that produce this should normally be mechanical quantities. The correct identification of these factors relies upon the observer having thorough background knowledge of the skill being assessed. In the second step of their model, Hay and Reid (1982) state that it is important to use all sensory information: visual, aural, tactile, and kinaesthetic to observe the performance. They also state that the position of the observer should be at right angles to the direction of the performer's body motion, and similar to Arend and Higgins (1976), Hay and Reid (1982) recommend observation of multiple trials to systematically observe separate parts of the movement. In identifying faults, it is suggested that the 'mechanical method' is used. This method is based upon identifying faults in the most fundamental biomechanical characteristics that contribute to execution of the movement. The third step in the model involves evaluating and ranking the faults. Hay and Reid (1982) suggest that faults should be prioritised according to the order that generates the most improvement in the time available to correct them. Hay and Reid (1982) recommend that in the final step of their model, instructions to the performer should be limited to one fault at a time. They also advocate initially providing direct corrections or literal descriptions of what the performer should do, rather than more figurative feedback.

McPherson (1990) provided yet another well known model of qualitative analysis of skilled movement. This model also consists of multiple phases, similar in structure and purpose to the phases described by Arend and Higgins (1976) and Hay and Reid (1982). McPherson's phases are; (1) pre-observation, (2) observation, (3) diagnosis, and (4) remediation. McPherson (1990) states that during pre-observation, careful development of an observation plan and a recording form are essential, and that during observation an optimal viewing location must be identified and used. Unique to this model, is the inclusion of the consideration of 'direct' and 'indirect' constraints. 'Direct' constraints relate to mechanical factors that directly affect how a movement is performed, while 'indirect' constraints refer to factors other than mechanical elements that may affect the performance of the skill, this might include motivational or environmental factors. Figure 2.28 provides a schematic representation of the phases of the model developed by McPherson (1990).

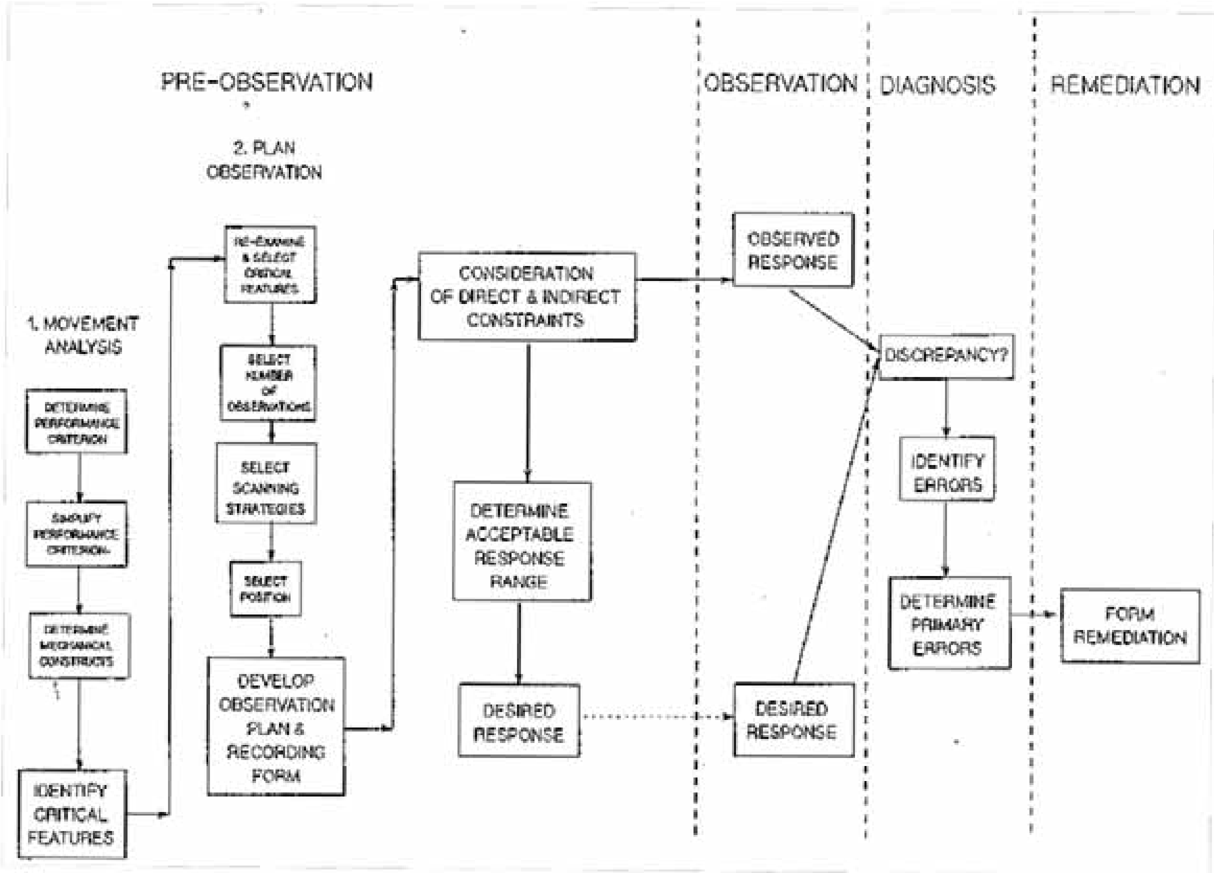


Figure 2.28 *Model of qualitative analysis of sports movement (from McPherson 1996, p s86).*

Lastly, Knudson and Morrison (1997) presented another multi-phase model consisting of; (1) preparation, (2) observation, (3) evaluation and diagnosis, and (4) intervention. Like the other models, Knudson and Morrison (1997) recommend careful preparation, including identification of "critical features", and use of an appropriate and systematic observation strategy, in which multiple observations (at least 5 – 8) are performed, using all perceptual senses. The distinguishing factor about this model is that the authors emphasise the importance of applying a more comprehensive and interdisciplinary approach during the final phases of the model. Rather than applying the traditional 'error detection and correction' strategy and overemphasising negative elements of the performance, Knudson and Morrison (1997) suggest that the analyst should strive to identify both the strengths and weaknesses of the performance and use all this information in applying useful intervention in the form of conditioning, cueing and modified practice (Knudson, 2000).

The four models discussed present many similarities in the phases and tasks that are seen as being necessary for a comprehensive approach to qualitative analysis. The multiphase approach to qualitative analysis in sports is thus a widely accepted model in the academic literature, however it is difficult to know whether the techniques presented are used regularly in everyday practice in sports pedagogy. It is possible that some sports coaches do not apply such systematic methods in analysing their students' movements, but rather rely on ad hoc methods developed over years of trial and error.

2.3.2.4 <u>Qualitative Analysis of Human Movement in Dance</u>

Students of dance and classical ballet usually undergo formal assessments or evaluations throughout their dance training. These assessments often take the form of examinations in which specific exercises or dances, developed as part of a syllabus, are evaluated by an external examiner who is registered with an examining organisation (*e.g.* Royal Academy of Dance (RAD), or Cecchetti). In these examinations, dancers are assessed against specific criteria, amongst which technique is usually only one component. Other components often include elements such as musicality and performance. The examinations held by organisations such as the RAD and Cecchetti are conducted regularly in dance centres throughout the world and provide a consistency of standard, within the parameters of the syllabus, against which dancers and dance teachers can be evaluated. Some dance organisations have devised their own assessment criteria for in-house assessment of their dancers. Again, these assessment tools usually list a number of different components, of which technique is only one element. Whether conducted by large external examining bodies, such as the RAD or Cecchetti, or through in-house assessment, it appears that the technique component in most dance assessments does not consist of detailed analyses of specific joint movements and/or segment orientations. For example, in the examinations conducted by the RAD, the technical elements that are assessed are listed as:

- Correct posture and weight placement
- Co-ordination
- Control
- Line
- Spatial awareness

- Dynamic values

(Royal Academy of Dance, 2011, p19)

For the Cecchetti syllabus the technical aspects of ballet are assessed according to these criteria:

- Stance and poise
- Use of technique
- An understanding of correct stance and placement with an application of classical technique

(Imperial Society of Teachers of Dancing, 2011, p12)

These values do not relate specifically to particular body regions, or to specific aspects of the technique, and are therefore somewhat difficult to interpret. A few in-house technique assessment tools used in tertiary dance institutions were also identified (Krasnow and Chatfield, 1997; Krasnow and Chatfield, 2009), and these proved to be just as ambiguous and non-specific in relation to assessing dancers' movement patterns at individual joints. Although these assessment methods typically give a numerical score, all judgments on the merits of a dancer's competence are based on subjective opinion through qualitative assessment. Dance assessment criteria used by Krasnow and Chatfield (2009) have included:

- Skill
- Space
- Time
- Energy
- Phrasing
- Presence

Krasnow and Chatfield (1997) assessed dancers according to the criteria of:

- Full body involvement
- Body Integration and Connectedness
- Articulation of Body Segments
- Movement Skills

There are a few dance research groups and organisations (Liederbach, 1997; Molnar and Esterson, 1997; Solomon, 1997; Siev-Ner *et al.*, 1997; Plastino, 2005; Hamilton, 2006; Potter and Baas, 2011; Gibbs *et al.*, 2006) who have devised tools for identification of potential pre-cursors to dance-related injury. Although often based largely on assessment and measurement of static postures, strength, and joint ranges of motion, some of these tools also include a section involving qualitative analysis of dynamic performance of core dance steps (Liederbach, 1997; Molnar and Esterson, 1997; Gibbs *et al.*, 2006; Potter and Baas, 2011). Molnar and Esterson (1997) developed a screening for students in a pre-professional ballet school. In addition to many static assessment techniques, this screening process included qualitative analysis of performance of the *plié*, *relevé*, *passé*, *developpé*, *battement tendu* and *ports be bras*. Elements such as “alignment” and “stability” were assessed through qualitative analysis of these movements. Liederbach (1997) described the contents of a ‘Screening for Functional Capacity in Dancers’ developed at the Harkness Centre for Dance Injuries, New York. Although also based largely on static postural and range of motion tests, the tool also included qualitative assessment of a few dynamic movements such as the *plié*, *sauté*, *jeté*, and *single pirouette*. Gibbs *et al.* (2006) presented guidelines for the ‘Post-Hire Health Screen for Professional Dancers’ developed by the Dance/USA Taskforce on Dancer Health. This screening tool contains a small section in which dance-specific movements (*i.e. plié* and *relevé*) are analysed qualitatively, with the aim of assessing lumbo/pelvic stability, mal-alignment of the knee with respect to the feet, and the position of the ankle joint (*i.e.* pronation/supination). Potter and Baas (2011) reported on the basic requirements for effective dance screening, and highlighted the work of the Dancer Wellness Project (DWP), a consortium of dance organisations, that promote dancer health. The screen developed by the DWP contains a dynamic functional assessment component, which includes qualitative analysis of the *battement tendu*, *developpé*, and *ports be bras*. Potter and Baas (2011) state that in assessing these movements, it is essential to ‘look’ for attributes of faulty movement patterning. Thus, it appears that greater awareness of the importance of assessment of dancers’ dynamic functional capacity is developing throughout the dance medicine and science community.

No matter which type of movement is being observed, or in which setting or field qualitative assessment is being conducted, the efficacy of any method or test used to assess human movement relies heavily on its reliability and validity (Spielholz *et al.*, 2001). The definitions and characteristics of test reliability and validity will be discussed in the next section.

2.3.3 Reliability and Accuracy of Qualitative Analysis of Human Movement

2.3.3.1 Definition of Test Reliability

The *reliability* of a test or measurement is the degree to which repeated measurements of the same trait are reproducible under the same condition (Morrow *et al.*, 2005). It relates to the consistency or repeatability of a measurement or observation. A test is said to be reliable if the same score or result is obtained each time the test is administered to the same individual by the same rater (intra-rater reliability) or by different raters (inter-rater reliability). The greater the dispersion of repeated scores of the same event, the greater the variance and the lower the reliability or repeatability (Toro *et al.*, 2003). A measure can be reliable but not valid, whereas an unreliable measure cannot be valid. In order to determine if an assessment has adequate reliability for the purposes of clinical or ergonomic use, one must understand what measures are used to determine reliability, what are the strengths and limitations of these measures, and what the results actually mean in the context of the field or discipline in which they are obtained (Innes and Straker, 1999).

2.3.3.2 Definition of Test Accuracy

The terms test “accuracy” and test “validity” are often used interchangeably in scientific research. In general, *validity* refers to the degree of truthfulness of a test score or result (Morrow *et al.*, 2005). That is, a test score or result, once found to be reliable, is valid if it accurately measures what it reports to measure. There are various levels of *validity*. The two broad categories of validity are *construct* validity and *criterion-related* validity. Construct validity is comprised of the two sub-categories of *face* validity and *content* validity. *Face* validity is concerned with how a measure or procedure appears. That is, it pertains to whether the test "looks valid" in that it seems like a reasonable way to gain the information the researchers are attempting to obtain. *Face* validity does not depend on established theories for support, it only requires an intuitive judgment. *Content* validity requires more rigorous statistical tests than face validity, and gives an indication of the degree to which the particular items in a test reflect the knowledge actually required for a given area of research (Toro *et al.*, 2003). In clinical practice for example, *content* validity refers to the relevance between the test items included on a performance rating scale and the common symptoms or pathologies of a particular condition. For example, numerous studies (Patla *et al.*, 1987; Hughes and Bell, 1994; Lord *et al.*, 1998; Schutte *et al.*, 2000; Romei *et al.*, 2004; Watelain *et al.*, 2005; Hillman *et al.*, 2007; Novacheck *et al.*, 2000) have investigated the *content* validity of visual gait analysis rating scales.

The *criterion-related* validity of test instruments, is a measure of agreement between the results obtained by the given test instrument and more "objective" results for the same population (Toro *et al.*, 2003). The "objective" results are obtained either by a well established instrument ("the gold standard") or by direct measurement. In terms of *criterion-related* validity in visual observation of human movement, data obtained from computerised 3D motion capture have come to be considered as “the gold standard" for *criterion-related* validity tests (Toro *et al.*, 2003), however other instrumented measurement techniques, such as inclinometry (Burdorf *et al.*, 1992; Teschke *et al.*, 2009; Village *et al.*, 2009), and electrogoniometry (Yen and Radwin, 2000; Ketola *et al.*, 2001; Spielholz *et al.*, 2001; Lowe, 2004a; Lowe, 2004b; Andrews *et al.*, 2008), have also been used to assess *criterion-related* validity. Assessment tools that can demonstrate *criterion-related* validity have the greatest justification for their use since they instil high confidence in their ability to genuinely reflect what is actually occurring. Thus, for the purposes of this study it is the *criterion-related* validity of qualitative analysis that will be used as a measure of “accuracy”. That is, qualitative analysis will be considered to be highly accurate if the data are in close agreement with *criterion-related* quantitative data.

2.3.3.3 Measurement of Test Accuracy and Reliability

Measures of reliability and validity are usually reported as coefficient values. Many reliability or validity coefficients are based on measures of correlation (*e.g.* Pearson’s Product-Moment Correlation Coefficient (*r*); Spearman Rank Correlation Coefficient (*r*); Intra-class Correlation Coefficient (ICC)). Correlation reflects the degree of association between data sets, and gives an indication of variance rather than agreement between data. For example, the greater the dispersion of repeated scores of the same event the greater the variance and the lower the reliability, and the smaller the variance between repeated scores the higher the reliability (Toro *et al.*, 2003). For many applications, however, it is necessary to determine agreement between measures (*i.e.* two sets of measures are the same). When the unit of measurement in an assessment is categorical (*e.g.* poor/ fair/good/ excellent; normal/abnormal; correct/incorrect), reliability or validity is more appropriately determined as a measure of agreement. In its simplest form this would be measured as *percentage agreement*, however this value often gives an over-estimation of true reliability (Innes and Straker, 1999). Another measure of agreement is the *kappa* (κ) statistic, which is used to correct for chance agreement. This statistic represents the average rate of agreement for an entire set of scores, and is an analysis of exact agreement with no room for 'close' agreement, making it suitable for nominal and ordinal data, but not continuous data (Innes and Straker, 1999). The weighted *kappa* takes into account the distance between categories. It penalises more for disagreement between extreme categories than for adjacent ones (Denis *et al.*, 2002).

Measure of Reliability or Validity	Range of Values	Interpretation of Values
Correlation Coefficients (*r*)	0.00 - 0.25	Little or no relationship
	0.26 - 0.50	Poor to fair
	0.51 - 0.75	Moderate to good
	> 0.75	Good to excellent
	≥ 0.90	Required for clinical application to ensure valid interpretation of findings
Intra-class Correlation Coefficient (ICC)	< 0.40	Poor reliability
	0.40 - 0.75	Fair to moderate reliability
	> 0.75	Good to excellent reliability
	≥ 0.90	Required for clinical application to ensure valid interpretation of findings
Kappa (*k*) value	0.00	Chance agreement
	0.01 - 0.20	Poor agreement
	0.21 - 0.40	Slight agreement
	0.41 - 0.60	Moderate agreement
	0.61 - 0.80	Substantial agreement
	0.81 - 1.00	Excellent to perfect agreement

Table 2.2 *Interpretation of measures of reliability or validity (Landis and Koch, 1977; Fleiss, 1986; Portney and Watkins, 1993)*

It appears that there is little consensus about which statistical methods are best to analyse reliability and validity (Bao *et al.*, 2009), however research has shown that *percentage agreement* values are generally higher than *kappa* values (van der Beek *et al.*, 1992; de Looze *et al.*, 1994; de Bruijn *et al.*, 1998; Burt and Punnett, 1999; Ketola *et al.*, 2001;

Denis *et al.*, 2002; Kociolek and Keir, 2010) and ICC values (Ebersole and Armstrong, 2006; Bao *et al.*, 2009), and perhaps overestimate the actual reliability and validity. Once a numerical measure of reliability or validity has been calculated, in the form of a coefficient or *kappa* value, typically a rating or interpretation is applied to this value. Correlation coefficients and *kappa* values can theoretically vary between 0 and 1.0, where 0 indicates no reliability and 1 indicates perfect reliability (Weir, 2005). Landis and Koch (1977) devised some guidelines for interpretation of particular ranges of *kappa* values, while other guidelines for interpretation of correlation coefficients and ICC coefficients and have also been developed, these are presented in Table 2.2.

Studies that have investigated the *criterion-related* validity or "accuracy" of qualitative analysis in human movement have used a variety of the above mentioned statistical methods to compare qualitative responses with quantitative data. *Kappa* values have been the most commonly used statistic in these studies (de Looze *et al.*, 1994; Ketola *et al.*, 2001; Paquet *et al.*, 2001; Nicholls *et al.*, 2003; Mackey *et al.*, 2003; Lowe, 2004a; Lowe, 2004b; Stott *et al.*, 2005; Dickens and Smith, 2006; Krosshaug *et al.*, 2007; Kawamura *et al.*, 2007; Dallas *et al.*, 2011), followed by Pearson's correlation coefficient (Yen and Radwin, 2000; Haupstein and Goldie, 2000; Spielholz *et al.*, 2001; Neumann *et al.*, 2001; McGinley *et al.*, 2003; McGinley *et al.*, 2006; Moseley *et al.*, 2008; Village *et al.*, 2009; Teschke *et al.*, 2009), and Spearman's rank correlation coefficient (Burdorf *et al.*, 1992; Harrison *et al.*, 1994; Lowe, 2004a; Lowe, 2004b; von Porat *et al.*, 2008). It appears that researchers are aware of the limitations of the measure of *percentage agreement* (P_o), as this statistic has only been reported in a few studies (de Looze *et al.*, 1994; Leskinen *et al.*, 1997; Paquet *et al.*, 2001; Piripis *et al.*, 2001; Read *et al.*, 2003; Brown *et al.*, 2008), with very few of these being conducted in recent years. As an alternative to the techniques listed above, some studies have obtained measures of accuracy based on calculation of mean error (Genaidy *et al.*, 1993; Hillman *et al.*, 1998; Morrison *et al.*, 2005; Plessner and Schallies, 2005; Krosshaug *et al.*, 2007; van Wyk *et al.*, 2009; Marques-Bruna *et al.*, 2008; Lau and Armstrong, 2011), or the number or percentage of accurate responses (Osborne and Gordon, 1972; Patla and Clouse, 1988; Baluyut *et al.*, 1995; Wren *et al.*, 2005; Andrews *et al.*, 2008; Passier *et al.*, 2010). Little evidence was found of the use of ICC for analysis of the accuracy of qualitative analysis in human movement.

The following section will review the findings of the studies on *criterion-related* validity or "accuracy" of qualitative analysis of human movement. These studies have been conducted in the clinical setting, in the field of ergonomics and human factors, and in various sporting disciplines. Considerable research has also been conducted on the inter-rater and intra-rater reliability of qualitative analysis of human movement, particularly in clinical practice, however this work will not be reviewed in this thesis. By definition, if an assessment technique has high *criterion-related* validity it will also have high reliability, whereas a highly reliable assessment tool may not necessarily be valid or accurate. For this reason, this review will focus only on studies that have assessed the *criterion-related* validity, hereafter referred to as "accuracy", of qualitative assessment of human movement. Articles have been selected for inclusion in the review if they contain results on the accuracy of visual observation methods in which kinematic variables (*e.g.* body segment and joint orientations) have been observed and compared with quantitative data obtained through instrumented measurement techniques.

2.3.4 Investigation of the Accuracy of Qualitative Analysis of Human Movement

Given the widespread use of qualitative analysis in routine clinical practice, in assessment of workplace postures, and in sports coaching, it is imperative that a high level of confidence is held in the accuracy of the techniques used. Studies investigating the accuracy of visual observation of human movement are therefore extremely important. The increasing availability of computerised motion analysis and other instrumented measurement techniques, has created the opportunity for more detailed study of the accuracy of observational assessment of human movement.

A number of studies have been conducted by clinical research groups to investigate the accuracy of the use of observational motion analysis scales. These studies have encompassed a wide diversity in both the type and number of variables selected for rating. Several studies (Hillman *et al.*, 1998; Piripis *et al.*, 2001; Read *et al.*, 2003; McGinley *et al.*, 2003; Mackey *et al.*, 2003; Wren *et al.*, 2005; Dickens and Smith, 2006; McGinley *et al.*, 2006; Kawamura *et al.*, 2007; Brown *et al.*, 2008) have used 3D quantitative motion analysis techniques to assess the accuracy of the observational gait analysis skills of clinicians working in musculoskeletal rehabilitation. These studies have investigated the accuracy with which raters are able to estimate specific joint angles

(Hillman *et al.*, 1998; Piripis *et al.*, 2001; Read *et al.*, 2003; Mackey *et al.*, 2003; Wren *et al.*, 2005; Dickens and Smith, 2006; Brown *et al.*, 2008), spatio-temporal properties (Mackey *et al.*, 2003) and kinetic parameters (McGinley *et al.*, 2003; McGinley *et al.*, 2006). Accuracy of visual observation of clinical functional performance tests has also been investigated (Harrison *et al.*, 1994; Bernhardt *et al.*, 1998; Haupstein and Goldie, 2000; Bernhardt *et al.*, 2002; von Porat *et al.*, 2008). Some of these studies have compared qualitative responses to 3D kinematic motion analysis data (Bernhardt *et al.*, 1998; Bernhardt *et al.*, 2002; von Porat *et al.*, 2008), while others have used force plate data (Harrison *et al.*, 1994; Haupstein and Goldie, 2000) or specifically designed equipment, such as an “instrumented foot plate” (Moseley *et al.*, 2008), to determine accuracy.

This section will also review the published research on the *criterion-related* validity of visual observation of work-related postures and movements. The accuracy of observational-based methods for assessing working posture has been investigated in several studies (Burdorf *et al.*, 1992; Genaidy *et al.*, 1993; de Looze *et al.*, 1994; Baluyut *et al.*, 1995; Leskinen *et al.*, 1997; Yen and Radwin, 2000; Paquet *et al.*, 2001; Spielholz *et al.*, 2001; Ketola *et al.*, 2001; Neumann *et al.*, 2001; Lowe, 2004b; Lowe, 2004a; Andrews *et al.*, 2008; van Wyk *et al.*, 2009; Teschke *et al.*, 2009; Village *et al.*, 2009; Xu *et al.*, 2011; Lau and Armstrong, 2011). These studies have been conducted by comparing analysts’ observational estimates of working postures with direct measurements of relevant joint angles. The methods of direct measurement have included 3D motional analysis (de Looze *et al.*, 1994; Leskinen *et al.*, 1997; Neumann *et al.*, 2001; Lowe, 2004b; Lowe, 2004a; Andrews *et al.*, 2008; van Wyk *et al.*, 2009; Xu *et al.*, 2011), electrogoniometer measurements (Yen and Radwin, 2000; Paquet *et al.*, 2001; Spielholz *et al.*, 2001; Ketola *et al.*, 2001; Baluyut *et al.*, 1995; Genaidy *et al.*, 1993), inclinometer measurements (Burdorf *et al.*, 1992; Teschke *et al.*, 2009; Village *et al.*, 2009), and more simplistic methods such as use of a plexiglass calibration board (Lau and Armstrong, 2011).

It appears that less research has been conducted on the accuracy of qualitative analysis of sporting activities than in clinical practice and occupational health and safety. Due to the highly varied nature of sports-related movements and the complexity of the movements involved, it may be more difficult to perform detailed studies on the accuracy of quantitative analysis of sports movement than for clinical gait analysis, functional performance tests, or work-related tasks. It is perhaps for this reason that it was difficult to find an abundance of studies that have used quantitative techniques to assess accuracy of qualitative analysis of sporting activities. However a few studies of this type were identified, which include investigation of qualitative analysis in gymnastics (Imwold and Hoffman, 1983; Plessner and Schallies, 2005; Dallas *et al.*, 2011), handball (Krosshaug *et al.*, 2007; Stensrud *et al.*, 2011), baseball (Nicholls *et al.*, 2003), soccer (Marques-Bruna *et al.*, 2008), and general physical education activities such the vertical jump (Knudson, 1999). The majority of these studies have obtained quantitative data through video analysis and 2D digitisation (Knudson, 1999; Plessner and Schallies, 2005; Marques-Bruna *et al.*, 2008; Stensrud *et al.*, 2011; Dallas *et al.*, 2011), while few studies have used 3D motion analysis (Nicholls *et al.*, 2003; Krosshaug *et al.*, 2007). Other techniques have included traces and measurements made from photographs (Imwold and Hoffman, 1983).

Investigation of the accuracy of qualitative analysis in dance, measured by comparison of qualitative data with quantitative data, has received no attention in the academic literature. A thorough review of the published academic literature on quantitative biomechanical assessment in dance, presented in Section 2.2, did not reveal any studies that specifically compared quantitative biomechanical data with qualitative responses based on observational assessment. In addition, literature searches in which accuracy or validity of qualitative analysis were key search criteria did not return any studies that focused on qualitative analysis in dance.

In total, 47 published studies were identified that have used instrumented quantitative methods to obtain *criterion-related* measures of validity (“accuracy”) of qualitative analysis of human movement. Figure 2.29 depicts the various percentages of the studies that have been conducted in relation to clinical practice, occupational health and safety, sports, and dance. Overall, the majority of these studies (41%) have been conducted in the clinical setting, with most of these clinical studies being related to qualitative gait analysis.

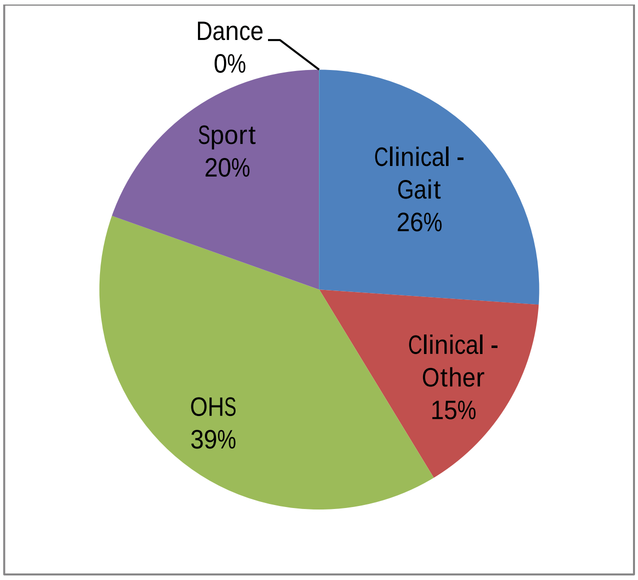


Figure 2.29 *Summary of percentages of studies conducted on the accuracy of qualitative analysis in clinical practice, occupational health and safety (OHS), sport, and dance.*

There is a great deal of diversity in the results for studies that have assessed accuracy of observation by comparing quantitative measurements with qualitative responses. *Kappa* (*k*) values have ranged from 0.01 to 0.94 ('poor' to 'excellent' agreement), Pearson's coefficients (*r*) have ranged from 0.24 to 0.98 ('little' relationship to 'excellent' relationship), Spearman's coefficients (*r*) have ranged from 0.37 to 0.62 ('fair' relationship to 'moderate' relationship), percentage agreement (P_o) values have ranged from 38% to 83%, and percentage of accurate responses have ranged from 20% to 95%. A variety of different protocols were used in the studies to obtain accuracy data for observation of various body regions, for subjects performing a multitude of different activities. Given the vast array of conditions under which these data were obtained, there are a number of factors that could have contributed to the diversity of accuracy results. The following sections will review the literature in relation to a number of key factors that may impact upon the accuracy results obtained. These factors include the mode of observation (*i.e.* live vs. video), the type of assessment scales used, the number of variables simultaneously observed, the body region observed, and the level of experience of the person conducting the qualitative analysis.

2.3.4.1 Effects of Observation Mode on Accuracy of Qualitative Analysis

The accuracy of observation of either video (Baluyut *et al.*, 1995; Yen and Radwin, 2000; Spielholz *et al.*, 2001; Neumann *et al.*, 2001; Lowe, 2004b; Lowe, 2004a; Andrews *et al.*, 2008; van Wyk *et al.*, 2009; Xu *et al.*, 2011) or live on-site (Burdorf *et al.*, 1992; de Looze *et al.*, 1994; Leskinen *et al.*, 1997; Ketola *et al.*, 2001; Paquet *et al.*, 2001; Teschke *et al.*, 2009) postural observation in the work place has been studied. It was not possible to identify any studies that directly compared the accuracy of observation between the two modes. From the data published to date, it appears that the only suitable comparison that can be made across studies to attempt to address this question is between Spielholz *et al.* (2001) and Ketola *et al.* (2001). Both these studies reported data on the accuracy of visual observation of wrist flexion/extension and radial/ulnar deviation, with a very similar number of joint angle categories. The difference between the studies is that Spielholz *et al.* (2001) used video observations, while Ketola *et al.* (2001) used live observations. For both studies only ‘poor’ correlation or agreement between observed and measured wrist joint angles was achieved. Spielholz *et al.* (2001) reported an average correlation coefficient for the wrist of 0.26, and Ketola *et al.* (2001) reported an average *kappa* value of 0.20. Thus, from this single comparison it could be suggested that the accuracy of visual observation of postures is similar whether observations are made via video recordings or live observations.

Most of the accuracy studies conducted in clinical practice to date have analysed ratings based on observations of subjects on video (Patla and Clouse, 1988; Harrison *et al.*, 1994; Bernhardt *et al.*, 1998; Hillman *et al.*, 1998; Haupstein and Goldie, 2000; Piripis *et al.*, 2001; Bernhardt *et al.*, 2002; McGinley *et al.*, 2003; Mackey *et al.*, 2003; Read *et al.*, 2003; Stott *et al.*, 2005; Wren *et al.*, 2005; Dickens and Smith, 2006; Kawamura *et al.*, 2007; Brown *et al.*, 2008; von Porat *et al.*, 2008; Moseley *et al.*, 2008). Only a few studies have investigated the accuracy of live observations (McGinley *et al.*, 2006; Passier *et al.*, 2010). Given the scarcity of studies that have investigated accuracy of live observations, and the diversity of protocols and assessment scales used, it is difficult to make many direct comparisons across live and video-based studies. Thus, only a few studies are helpful in making comparisons across these modes of observation. McGinley *et al.* (2003) asked experienced physiotherapists to watch video recordings of post-stroke hemiplegics and rate their level of ankle push-off during terminal stance of gait. The observer's ratings were correlated with ankle kinetic data (peak ankle power) obtained from 3D motion analysis. High correlations between the observational ratings and the criterion measure were reported (mean Pearson r = 0.84), representing 'fair to excellent' values. McGinley *et al.* (2006) also investigated the accuracy of observation of ankle push-off in post stoke hemiplegics, however in this study raters viewed the subjects under live real-time conditions, rather than observations of videos. The same protocol, rating scale and *criterion-related* measure were used as in McGinley *et al.* (2003). A strong positive linear relationship between the observed data and 3D kinetic data (mean Pearson r = 0.91) was also obtained for the live observations. Comparison of validity results obtained from McGinley *et al.* (2003) with those from McGinley *et al.* (2006) demonstrates that under comparable conditions, the accuracy of rating ankle push-off in terminal stance is similar for videotaped and live observations.

Wren *et al.* (2005) appears to be the only other research group that has investigated and compared accuracy results for visual gait observations obtained from live and video-based observation techniques. Results showed that accuracy of joint angle estimates was similar for ratings made from normal speed videos and live observation. An additional element of this study was to compare the effects of video playback speed on accuracy of observation. For items where accuracy was especially poor at normal speed (*e.g.* ankle dorsiflexion of less than 5º), greater accuracy was obtained when viewing the slow speed video. Moseley *et al.* (2008) also investigated the effects of video play back speed on accuracy of qualitative analysis. For this study of the accuracy of observation of the ankle joint movement of able bodied subjects during stair descent, results also indicated that greater accuracy of observation was obtained when viewing the videos in slow motion (mean r = 0.40) compared to normal speed (mean r = 0.30).

In relation to investigation of accuracy of qualitative analysis in sporting activities, most studies (Imwold and Hoffman, 1983; Knudson, 1999; Nicholls *et al.*, 2003; Morrison *et al.*, 2005; Plessner and Schallies, 2005; Krosshaug *et al.*, 2007; Marques-Bruna *et al.*, 2008; Dallas *et al.*, 2011) have investigated accuracy of video analysis, while only one study (Stensrud *et al.*, 2011) looked into the accuracy of live observational analysis. It is therefore difficult to make valid comparisons of the accuracy of live and video-based qualitative analysis in sport.

Given such wide use of video based assessments in qualitative analysis, it is important to understand the effects that the position of the camera in relation to the joint angles of interest have on the accuracy of visual observation. Some very recent studies in workplace posture analysis (Lau and Armstrong, 2011; Xu *et al.*, 2011) have attempted to study this.

Lau and Armstrong (2011) aimed to investigate whether wrist flexion/extension and radial/ulnar deviation postures were estimated differently when different viewing angles were used. A single digital video camera was used and placed in three different camera angle positions, (1) the 'ideal' camera angle, placed orthogonal to the plane of motion, (2) the 'in-line' view, placed directly in the plane of joint motion and through the axis of rotation, and (3) the 'off-axis' view, placed neither orthogonal nor in-line with the plane of motion of the observed joint. For measures of accuracy, observation data were compared with joint angle measurements obtained using a plexiglass calibration board. Results showed that the viewing angle of the camera did affect the accuracy of visual observations. Observations from the orthogonal camera angle produced the most accurate observations, while the in-plane views produced the least accurate observations. The authors therefore confirmed that the orthogonal view is preferable and in-plane views should be avoided, however, if possible, use of multiple cameras for video-based observation methods is preferred. Xu *et al.* (2011) also provided evidence to indicate that the viewing angle of the camera does affect accuracy of visual observation of video-based posture assessment tools. In this study one digital video camera was placed such that a side-view of the subject was obtained. Participating raters were asked to observe trunk flexion/extension and side flexion, as well as flexion/extension of the shoulder, elbow, knee and ankle joints. Visual observation data were compared with 3D motion analysis data to obtain a measure of observation accuracy. The estimated joint angles were strongly correlated with the measured segment angles for all the observed angles ($r > 0.8$), except the trunk side flexion angle ($r = 0.21$), the only variable for which the camera was not placed orthogonal to the plane of motion. In agreement with Lau and Armstrong (2011), Xu *et al.* (2011) also suggested that use of multiple cameras placed at different camera angles would optimise accuracy of visual observation data obtained using video-based posture assessment tools.

The effects of video camera angle on the accuracy of qualitative analysis has also been studied in relation to sporting activities, in particular to judging gymnastics (Plessner and Schallies, 2005; Dallas *et al.*, 2011). Plessner and Schallies (2005) examined the influence of camera angle on the accuracy of judgements of the angle of deviation from the horizontal of the abducted arms for male gymnasts performing the 'cross' on the rings. Results showed that even experienced judges were significantly influenced by their viewing position, with their error rate increasing with increasing deviation of the camera angle from a frontal view. Dallas *et al.* (2011) also asked judges to estimate the degree of deviation from the horizontal of the abducted arms, however it was for the 'inverted cross'. Three different camera positions were used to study the accuracy of observation, and in agreement with Plessner and Schallies (2005), results indicated that perceptual errors in the judges' evaluations were systematic with regard to angle of observation, with unacceptable accuracy being obtained when using an observation angle of 45º to the frontal plane.

Thus, review of the studies that have investigated the effects of the mode of observation on the accuracy of qualitative analysis of human movement, reveals little convincing evidence to suggest there are significant differences in accuracy when observation is conducted via live or video-based methods. However, if video-based methods are used, results indicate that better accuracy of observation is obtained using slow playback speed, rather than normal playback speed. Furthermore, there is strong evidence to suggest that the viewing angle does have an effect on accuracy of observation, indicating that the position of the camera or live viewer are of utmost importance in obtaining accurate evaluations.

2.3.4.2 Effects of Scale Type on Accuracy of Qualitative Analysis

There is much diversity in the type of assessment scales or techniques used in qualitative analysis of human movement. When considering all the studies identified from the fields of clinical practice, occupational health and safety (OHS), and sport that have investigated the accuracy of qualitative analysis, the majority of studies (65%) have used nominal or categorical scales. Interval scales, visual analogue scales (VAS) and specific numerical estimates have also been used, however much less frequently. Figure 2.30

displays the percentages of the studies that have used each of these different assessment scale types or techniques.

In terms of the use of particular scales in studies conducted in each setting or field, all scales types were used in studies conducted in clinical practice, while only categorical scales and numerical estimates were used in OHS studies, and all scales except interval scales were used in studies of accuracy of qualitative analysis in sport. Table 2.3 summarises the types of scales studied in each of the different fields.

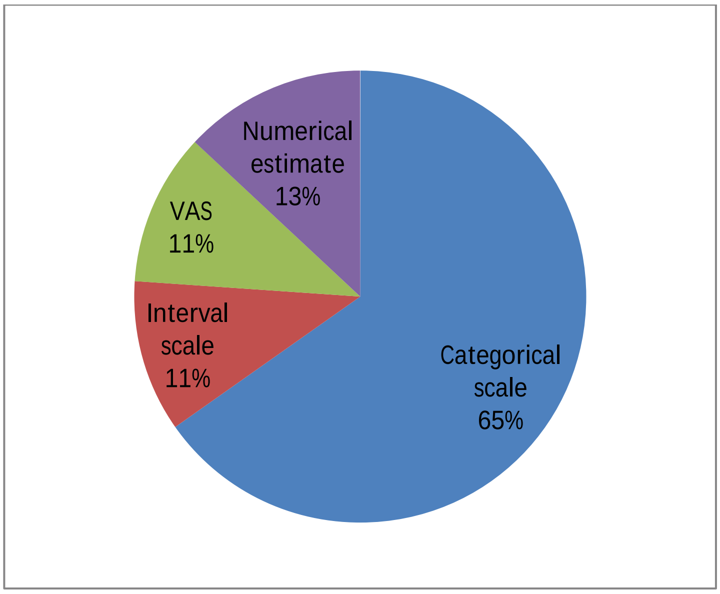


Figure 2.30 *Summary of percentages on studies that have used categorical scales, interval scales, visual analogue scales (VAS), or numerical estimates for qualitative analysis of human movement.*

	Clinical	OHS	Sport
Categorical scale	10	15	5
Interval scale	5	0	0
Visual Analogue Scale	2	0	3
Numerical estimate	2	3	1
Total	**19**	**18**	**9**

Table 2.3 *Summary of the numbers of studies that have used categorical scales, interval scales, visual analogue scales (VAS), or numerical estimates for qualitative analysis of human movement in various fields.*

It is possible that the type of scale used in a visual observation tool may affect the accuracy of the observations obtained. When choosing an appropriate method for visual observation of human movement, it is therefore important to consider the type of data recorded and which type of scale or data recording technique can capture this information most accurately. Thus, review of results obtained from studies using different rating scales may offer some insight into how the scale or number of categories used may affect accuracy.

In relation to nominal or categorical scales, it is evident that various numbers of categories are typically used, ranging from binary nominal scales through to scales with as many as nine categories. Central to the observational methods that use joint angle categories to record postural information, is the effect that the number or size of categories has on the accuracy of the observation data recorded. A variety of studies have investigated the effects on accuracy of the number of categories in nominal scales (Leskinen *et al.*, 1997; Piripis *et al.*, 2001; Lowe, 2004a; Lowe, 2004b; Village *et al.*, 2009; van Wyk *et al.*, 2009).

In the clinical setting, Piripis *et al.* (2001) and Lowe and colleagues (2004a; 2004b) have investigated the question of how the number of posture categories may affect accuracy. Piripis *et al.* (2001) studied the accuracy of observational gait analysis using the Hugh Williamson Gait Analysis Scale (HWGAS). It was reported that accuracy of observation of foot position during stance was better when using a 5 category scale ($P_o = 0.67$) compared to a 7 category scale ($P_o = 0.46$). Lowe *et al.* (2004a; 2004b) studied the effects of the number of posture categories on the accuracy of visual observation of shoulder, elbow, forearm and wrist postures. All joint postures were assessed with a 3-category scale and a 6-category scale. Observations of video data were compared with data from electrogoniometer measurement, and results indicated that, with the exception of shoulder elevation, accuracy of visual observation was better when using a 3-category scale ($r = 0.44 – 0.67$), compared to the 6-category scale ($r = 0.07 – 0.27$).

The effects of the types of labelling included or omitted from scales has also proven to be influential in clinical practice. Accuracy of observational gait analysis has been studied using various categorical ratings scales (Mackey *et al.*, 2003; Wren *et al.*, 2005; Dickens and Smith, 2006; Kawamura *et al.*, 2007; Brown *et al.*, 2008). For each of these scales the observers gave their qualitative response by selecting one of a small number of joint range categories. In modified versions of the Physician's Rating Scale (PRS), used by Mackey *et al.* (2003), Dickens and Smith (2006) and Brown *et al.* (2008), as well as providing joint angle ranges the category definitions also contained labels indicating which was the "normal" range and how the other ranges deviated from normal (*e.g.* "severe flexion", "mild flexion"). However, in Wren *et al.* (2003), joint angle categories were given without any indication as to how each category related to normal. In contrast, Kawamura *et al.* (2007) used a rating scale in which observers were not provided with any specific joint angle categories, but instead were only provided with references to "normality". On comparison of the results of Mackey *et al.* (2003), Read *et al.* (2003), Wren *et al.* (2005), Dickens and Smith (2006), Kawamura *et al.* (2007) and Brown *et al.* (2008), it appears that greater accuracy was obtained for observational gait analysis when raters were provided with rating scales that contained specific joint angle categories as well as labels to indicate the level of normality associated with each joint range category. Neither the joint range categories alone, nor the references to normality alone seemed to assist raters in achieving accurate results.

Overall, in considering data from a variety of studies that have investigated the effects of different scale types, it appears that better accuracy of qualitative analysis is obtained when fewer categories are used, and when categories are adequately labelled with appropriate references to normality or levels of competency.

2.3.4.3 Effects of Number of Parameters Observed on Accuracy of Qualitative Analysis

The number of posture or movement parameters that raters are asked to observe at one time may also have an effect on the accuracy of visual observations of human movement. A few studies have attempted to investigate the effect of the total number of parameters observed on the accuracy of postural assessment in the workplace. Leskinen *et al.* (1997) conducted a study in which visual observations of neck and trunk flexion of workers performing manual handling tasks were compared with 3D motion analysis data. A total of six different parameters were observed in the study, however four different trial types were conducted, consisting of different combinations of parameters. In one trial type, subjects were asked to observe all six parameters. In addition to neck and trunk flexion, these parameters included the size of the load lifted, the type of lift performed, whether the hands were elevated above or below the shoulder, and whether the subject was kneeling or squatting. In two trial types the number of parameters observed was limited to four, and in one trial type subjects were asked to observe only two parameters. Results showed that percentage agreement between visual observation data and 3D motion analysis data for neck flexion was better when only two parameters were observed (P_o = 0.53) than when six parameters were observed (P_o = 0.39). However for trunk flexion, the effect of the number of observed variables was not so clear. For the two trial types that contained four observation parameters, proportion of agreement for trunk flexion was 0.59 and 0.68, while for the trial type containing six parameters, proportion of agreement was 0.61. Perhaps these data suggest that once a certain number of observation parameters are added to an observation tool, there is limited effect on the accuracy of observation, but keeping the number of observation parameters very small (*i.e.* only two), does enable improved accuracy of visual observation.

Paquett *et al.* (2001) investigated the validity of visual observations when using the Posture, Activities, Tools and Handling (PATH) tool (Buchholz *et al.*, 1996), and also a simplified version of PATH. For the full PATH method, raters were required to record nine different parameters, but for the simplified version of PATH, the observers used the same template but were required to record data for only three postural parameters. A measure of accuracy of the visual observation data for the tools was obtained by comparing it with inclinometer and electrogoniometer data. In general, agreement with the reference measurements was slightly higher for the simplified PATH tool (k = 0.60 - 0.87) than with the full PATH method (k = 0.51 - 0.74). However, it should be noted that each observer was assigned to perform either the simplified PATH or full PATH for the duration of the study. It is therefore possible that the differences found may be due to inter-observer differences rather than to the decreased cognitive demands of the simplified PATH method. Nevertheless, the authors were confident in suggesting that the "accuracy of posture observation may improve when the observer is required to code fewer parameters".

In sports analysis, the effect of the number of parameters observed on accuracy of observation has been studied in gymnastics (Imwold and Hoffman, 1983; Plessner and

Schallies, 2005). Imwold and Hoffman (1983) asked raters to observe either two, three or four different parameters related to the running front handspring. Decreasing accuracy was obtained with increasing number of observation targets. Plessner and Schallies' (2005) study required both experienced and inexperienced gymnastics judges to estimate arm angles during performance of the 'cross'. In some trials, estimation of arms angles was the only observation required, while in others, observers were also required to estimate the duration that the position was held. Data indicate that there was no statistically significant main effect of the number of tasks on the accuracy of observation.

Thus, data suggests that when asked to estimate more than two parameters, accuracy of observation decreases as the number of observation targets increases, but there is little difference in accuracy of observation between one and two observation targets.

2.3.4.4 Effects of Body Region Observed on Accuracy of Qualitative Analysis

A variety of studies have reported data to suggest that the level of accuracy of observation of human movement is dependent upon which joints or body regions are being observed. In relation to workplace posture, Baluyut *et al.* (1995) compared video-based visual observation data with goniometric measurements. Data for the percentage of correct responses (P_c) indicate that it was harder for subjects to accurately evaluate postures of the distal joints, such as the elbow (P_c = 53 – 82%) and wrist (P_c = 65 – 80%), than for the shoulder (P_c = 54 – 92%), neck (P_c = 76 – 95%) and lower back (P_c = 71 – 98%). Lowe and colleagues (2004a; 2004b) also reported that estimates of shoulder elevation (r = 0.67) were generally more accurate than estimates of the more distal movements of elbow flexion (r = 0.45), forearm supination (r = 0.46), and wrist flexion (r = 0.44). These data were obtained by comparison of visual observation data with electrogoniometer data. A few accuracy studies (Spielholz *et al.*, 2001; Ketola *et al.*, 2001) have focused primarily on observation of the distal upper limb joints. Spielholz *et al.* (2001) compared wrist and forearm posture estimates obtained from observation of video images with data from electrogoniometric measurements. Pearson's correlation coefficients were low for all variables, but were worse for forearm pronation/supination (r = 0.07), compared to wrist flexion/extension (r = 0.33) and wrist radial/ulnar deviation (r = 0.21). Ketola *et al.* (2001) also investigated the validity of visual observation of wrist postures by comparison with electrogoniometric measurements. Results were consistent with those of Spielholz *et al.* (2001) with only 'poor to fair' agreement obtained for all wrist postures (k = 0.04 – 0.38).

Other workplace studies (Burdorf *et al.*, 1992; Leskinen *et al.*, 1997; Paquet *et al.*, 2001; Neumann *et al.*, 2001; Xu *et al.*, 2011) have looked mainly at the accuracy of observation of the trunk, neck and shoulder joints. Burdorf *et al.* (1992) compared visual observations of trunk 'bending' with inclinometric measurements, and calculated 'moderate' correlations between the two methods for sedentary (r = 0.62 and dynamic (r = 0.57) tasks. Leskinen *et al.* (1995) reported that estimations of trunk flexion angles (P_o = 0.63) were more accurate than estimations of neck flexion angles (P_o = 0.46), as judged by comparison of visual observation data with 3D motion analysis data obtained by Selspot II equipment. Paquet *et al.* (2001) obtained higher accuracy for visual observation of shoulder (k = 0.75 – 0.80) postures compared to trunk postures (k = 0.51 – 0.60). These data were obtained by comparison of live visual observation data with electrogoniometer and inclinometer data. Very recently, Xu *et al.* (2011) also investigated the accuracy of visual observation of trunk and shoulder angles, however in this study accuracy results were similar for observation of these different body regions. By comparing visual observation data with 3D motion analysis data, Pearson's correlation coefficients (r > 0.83) indicated 'good to excellent' validity for observations of sagittal plane trunk and shoulder postures. Validity of observation of trunk flexion/extension was studied by Neumann *et al.* (2001) through comparison of observation of static video images with 3D motion analysis data. The observational data showed very high correlation with data from the 3D motion analysis system (r = 0.92). Collectively, the results of studies investigating the validity of visual observation of work task postures indicate that accuracy of observation is weakest for distal upper limb joints, such as the wrist, forearm and elbow, and is most accurate for observation of trunk or lower back postures. Results have varied with respect to the relative accuracy of shoulder, trunk and neck observations.

Studies have also been conducted in clinical practice in relation to the accuracy of observations of movements at different joints of the body. Read *et al.* (2003) reported that ankle dorsiflexion in swing showed the best percentage agreement (83%) between the visual score and the quantitative motion analysis data. The proximal recordings of peak hip extension in stance, peak hip flexion in swing, and pelvic rotation in mid-stance were also all well correlated (75%, 68%, and 69%, respectively), however the knee observations in the sagittal plane showed lower correlations of 60% for peak knee flexion in swing, 55% for knee extension in terminal swing, and 47% for peak knee extension in stance. These results indicate that it was most difficult for observers to estimate joint angle magnitude at knee level during gait. Mackey *et al.* (2003), showed a 'moderate to substantial' level of agreement between data from 3D gait analysis and observational data for knee position in mid-stance (average k = 0.57), initial foot contact (average k = 0.59), foot position in mid-stance (average k = 0.64), and timing of heel rise (average k = 0.65). Like Read *et al.* (2003), Mackey *et al.* (2003), also reported higher correlations for the items relating to foot position than for knee position. However, both Wren *et al.* (2005) and Kawamura *et al.* (2007), reported that contrary to previous studies (Read *et al.*, 2003; Mackey *et al.*, 2003), accuracy was greatest for knee position and lowest for hip and ankle positions. In Wren *et al.* (2005), accuracy was particularly poor when ankle dorsiflexion was less than 5º. Thus, although overall accuracy was better for the knee than for the ankle or hip, the level of accuracy did depend on the degree of knee flexion demonstrated by the subjects. For the knee, raters assigned appropriate ratings in 73%-83% of cases when flexion was greater than 20º, in 61%-75% of cases between 5º and 20º of flexion, and only 11% - 20% when the knee was close to neutral. That is, raters had more difficulty categorising knee position when it was close to neutral.

A few workplace studies (Baluyut *et al.*, 1995; Yen and Radwin, 2000; Village *et al.*, 2009; Teschke *et al.*, 2009) have investigated accuracy of observation of neutral versus non-neutral joint postures. Results from a study by Baluyut *et al.* (1995), in which visual estimates of joint angles were compared with goniometric measurements, indicate that joint angle observations are more accurate for larger deviations from the neutral position. This was found to be the case for trunk flexion, shoulder flexion, wrist flexion and elbow flexion especially. Percentage correct response data for neutral and extreme joint positions were 71% and 98% for trunk flexion, 54% and 77% for shoulder elevation, 55% and 82% for elbow flexion, and 65% and 85% for wrist flexion. Yen and Radwin (2000) compared visual observation data with data obtained from electrogoniometers to assess the *criterion-related* validity of visual observations of work task postures of the shoulder, elbow, forearm and wrist. Subjects observed static frames of video recordings of workers performing six industrial jobs. Overall, the Pearson correlation coefficient for comparison between visual observation and electrogoniometric measurement was 0.75. When considering only larger joint motions that exceeded the posture classification angle resolution, the correlation between postural classification and electrogoniometer data increased to 0.82. Village *et al.* (2009) also presented data to indicate that visual observation is more accurate the further the joint postures deviate from the neutral position. By comparing data obtained from observation of static video images with data from an inclinometer, these authors found that Pearson correlation coefficients for validity of trunk flexion observations increased as the range of motion increased (0 - 10° flexion, $r = 0.13$; 10 - 20° flexion, $r = 0.16$; 20 - 45° flexion, $r = 0.19$; 45 - 60° flexion, $r = 0.42$; > 60° flexion, $r = 0.90$). Teschke *et al.* (2009) also reported that accuracy of visual observation of trunk flexion increased with increasing displacement from the neutral position. This study also compared observation data with inclinometer data, and correlation coefficients increased as flexion angle categories increased from 10 - 20° ($r = -0.052$), to 20 - 45° ($r = 0.12$) to >60° ($r = 0.90$).

With regards to sporting activities, for men's gymnastics Plessner and Schallies (2005) and Dallas *et al.* (2011) both investigated the accuracy of observation of the deviation of the arm position from the horizontal during performance of the upright (Plessner and Schallies, 2005) and inverted (Dallas *et al.*, 2011) 'cross'. Plessner and Schallies (2005) reported similar levels of accuracy for arm positions with true deviations of 0 - 15°,16 - 30°, 31 - 45° and <45° from the horizontal, however Dallas *et al.* (2011) found that the degree of angular deviation did affect accuracy. Dallas *et al.* (2011) reported that percentage accuracy was best when the true angular deviation was 31 - 45° (74%), followed by 16 - 30° (65%) and least accurate for 1 - 15° deviation (56%).

Overall, data from studies investigating workplace activities indicate that distal joint movements of the upper limb are more difficult to accurately observe than proximal joint movements, however in clinically related studies of the lower limb, results to not provide strong evidence to suggest that a particular joint or region of the lower limb is usually more accurately observed than another. There is however, convincing evidence to indicate that the degree of deviation of a joint from neutral does affect accuracy of observation, with accuracy increasing with increasing deviation from neutral.

2.3.4.5 Effects of Observer Experience on Accuracy of Qualitative Analysis

The effect of observer experience on accuracy of qualitative analysis has also received some attention in the academic literature. A few authors (Bernhardt *et al.*, 2002; McGinley *et al.*, 2003; Brown *et al.*, 2008) have investigated this relationship with respect to clinical assessment tools. Bernhardt *et al.* (2002) investigated the influence of clinical experience on the accuracy of observational kinematic assessment of upper limb function and found that all groups of observers ("highly experienced", "less experienced" and "novice") made moderate to highly accurate judgments with no significant differences between groups. Similarly, McGinley *et al.* (2003) found no evidence of a relationship between clinical experience and accuracy of observational analysis in their investigation of the accuracy of assessment of ankle push-off during terminal stance in gait. Most recently, Brown *et al.* (2008) reported that in the hands of experienced observers observational gait analysis showed better percentage agreement with 3D motion analysis data (57.75%) than when assessed by inexperienced observers (49.5%). However, the difference between the two groups was only 8.25%. Having had no previous experience in observational gait analysis, the inexperienced observers improved their accuracy in a second observation in all categories except for knee peak flexion in swing. In contrast, Moseley *et al.* (2008) did report a difference in accuracy of observation due to the level of experience of the observer. In this study, in which participants observed the ankle joint movement of able bodied subjects during stair descent, results indicated that greater accuracy of observation was achieved by neurological physiotherapists who had experience in observational gait analysis (Pearson's $r = 0.39$) compared to cardiothoracic physiotherapists (Pearson's $r = 0.26$) and undergraduate physiotherapy students (Pearson's $r = 0.23$) who had little or no experience in observational gait analysis.

As was the case for the clinical setting, only a few studies (Lowe, 2004a; Andrews *et al.*, 2008) were identified that specifically investigated the effect of observer experience on accuracy of visual observations of work-related postures. Lowe *et al.* (2004a) reported that analyst's self-reported years of experience in the field of ergonomics exhibited no meaningful correlation with posture estimation accuracy for the elbow and shoulder. Andrews *et al.* (2008) examined the effect of rater experience or expertise level on the effect of classification of trunk postures by visual observation. Three groups of participants were recruited, two novice groups and one expert group. The difference between the novice groups was that one group had completed courses in functional human anatomy, while the other group had not. Trunk flexion/extension and lateral side flexion postures were classified by observation of static video frames. To determine the level of accuracy of posture classifications, observation data were compared with the actual joint angles, as measured by 3D motion analysis (Isotrak^{TM}). The authors hypothesised that more posture classification errors would be made by novice operators compared to experts. Results showed that there were significant differences between groups in the percentage of misclassification errors ($p < 0.001$) for trunk flexion/extension. Both novice groups obtained greater percentages of misclassification than the expert group, but interestingly, it was the Novice 2 group (those who had completed an anatomy course) rather than the Novice 1 group (those with no anatomy training) who obtained the highest percentage of misclassification of all groups. For observation of lateral trunk flexion all groups had similar percentages of misclassification errors. Results of the few studies that have investigated the effects of rater experience on visual observation of work task postures are mixed and therefore appear to be inconclusive. Lowe *et al.* (2004a) reported that experience had no effect on accuracy of visual observations, while data from Andrews *et al.* (2008) suggest that the effect of rater experience may vary, depending upon which joints of planes of motion are being observed.

In relation to sporting activities, only three articles were found that specifically looked at the effect of experience on accuracy of qualitative analysis (Imwold and Hoffman, 1983; Knudson, 1999; Plessner and Schallies, 2005). Results of these studies have varied. Imwold and Hoffman (1983) reported that experience does improve the observational analysis of a gymnastics skill, the running front handspring, with specialist gymnastics coaches only achieving 54% accuracy, compared to 46% accuracy by generalist physical education teachers and undergraduate physical education students. Also in relation to assessment in gymnastics, Plessner and Schallies (2005) found that experienced judges (mean experience = 15.4 years) were more accurate than novices in their estimates of arms angles when observing male gymnasts perform the ‘cross’. In contrast, Knudson (1999) revealed that 60% of students were effective in rating joint range of motion during the vertical jump, compared to only 20% of highly experienced professionals. So, it seems that collectively, studies conducted in multiple fields have not provided convincing data to definitively indicate that experience is or is not advantageous for increasing the accuracy of qualitative analysis of human movement.

Table 2.4 summarises the conclusions drawn from the literature review on the *criterion-related* validity or accuracy of qualitative analysis of human movement.

Factor	Conclusions from Review of Literature
Mode of observation	Data are inconclusive as to whether better accuracy is achieved when using live or video-based observation techniques.
Video playback speed	Accuracy is improved when slower video playback speeds are used.
Camera or viewing angle	Camera angle or position of the observer in relation to the plane of joint movement significantly affects accuracy of observation.
	Better accuracy is obtained when the camera angle and plane of movement are orthogonal to each other.
Number of scale categories	Better accuracy is obtained when fewer scale categories are used.
	Better accuracy is obtained when categories are adequately labelled, for example with appropriate references to normality or levels of competency.
Number of parameters observed	Accuracy decreases as the number of simultaneous observation targets increases.
Body region observed	Distal upper limb joint movements are more difficult to accurately observe than proximal upper limb joint movements.
	Data do not strongly suggest that a particular joint or region of the lower limb is more accurately observed than another.
	Accuracy increases with increasing deviation of a joint angle from its neutral position.
Observer experience	Results are inconclusive as to the effect of observer experience on accuracy of qualitative analysis.

Table 2.4 *Summary of conclusions from literature review of accuracy of qualitative analysis of human movement.*

2.4 Summary of Literature Review and Project Rationale

2.4.1 Summary of Literature Review

This chapter has presented a review of the literature on: the development of classical ballet technique; the fundamental biomechanical principles that characterise classical ballet technique; instrumented quantitative biomechanical analysis of theatrical dance styles; and the characteristics, application, and accuracy of qualitative analysis of human movement. The following is a summary of the key findings:

- The fundamental principles of classical ballet technique have their origin in historical context and have evolved over a period of nearly five centuries. Since its inception in 15^{th} century Europe, development and refinement of classical ballet technique occurred in response to stylistic and functional necessity.

- According to the historic and current dance literature, professional ballet dancers must possess: the technical attributes of grand manners; codified foot positions; extreme turnout of the lower limb; elevation and *pointe* work; and extreme flexibility displayed through maximum extension of the lower limbs. These characteristics can be summarised into four fundamental principles of classical ballet technique.

- The four fundamental principles of classical ballet technique, and their defining characteristics were identified as:

  1) 'Alignment' - maintaining verticality of the torso
  2) 'Placement' - minimal displacement of the pelvis from a centred position
  3) 'Turnout' - maximum external rotation of lower limbs
  4) 'Extension' - maximum elongation of the lower limbs

- Quantitative instrumented analysis of dance movement is a relatively new field of academic research. The vast majority of research has occurred from 2000 onwards, with a considerable increase in publications since 2005. Use of 3D motion analysis of dance has increased substantially since 2005.

- The majority of quantitative dance analysis studies have investigated the dance genre of classical ballet. However, of these, only 11 published studies were identified that used 3D motion analysis to report kinematic data for classical ballet. Amongst these 11 studies, no single study used 3D motion analysis to analyse classical ballet technique across multiple steps in terms of a set of fundamental biomechanical principles of the technique.

- A quantitative tool, based on 3D motion analysis, for assessment of classical ballet technique was not identified in the academic literature.

- Qualitative analysis is a form of movement assessment typically applied in clinical practice, in the fields of occupational health and safety and ergonomics, in sports analysis and coaching, and in dance assessment and instruction.

- Studies investigating the accuracy of qualitative analysis of human movement have been conducted in the clinical setting, in relation to workplace tasks, and for some sporting activities. Studies on the accuracy of qualitative analysis of dance movements were not identified in the academic literature.

- A number of factors affect the accuracy of qualitative analysis of human movement. These include: camera or viewing angle; video playback speed; number of scale categories; number of parameters observed; and body region observed.

- Data are inconclusive as to the effect of mode of observation (*i.e.* video vs. live), and observer experience on the accuracy of qualitative analysis of human movement.

2.4.2 Project Rationale

It is evident from the literature that the requirements for execution of correct classical ballet technique can be succinctly defined by a few key theoretical principles. These theoretical principles can be translated into four fundamental biomechanical principles, each of which can be defined in terms of specific kinematic variables. The number of scientific studies involving 3D quantitative motion analysis of classical ballet technique has steadily increased since 2005, however no studies were identified that used 3D motion analysis to assess the technique in relation to a number of fundamental principles across multiple ballet steps. Moreover, the existing published literature has not attempted to compare professional level practical execution of classical ballet technique with the key theoretical principles outlined in the dance-related literature. Thus, the current study will redress this anomaly in the scientific literature. To do this, 3D motion analysis will be conducted on professional and non-professional ballet dancers performing seven categories of ballet steps. The aim will be to compare the practical kinematic data relating to each of the fundamental biomechanical principles of the classical ballet technique with the theoretical ideals presented in the literature. It is proposed that the findings of such a study could have implications for the teaching practices currently used in instruction of classical ballet technique.

Review of the literature also highlights that qualitative analysis of human movement is used routinely in clinical practice, occupational health and safety, and for instruction of sport and dance, and is therefore a very important skill that should be performed with a high degree of accuracy. Studies investigating the accuracy of qualitative analysis were identified in relation to clinical practice, occupational health and safety, and sport, but not for qualitative analysis of dance. This finding thus identifies another area in which scientific investigation is warranted, but is currently lacking. An additional aim of this research project therefore is to investigate the accuracy with which ballet teachers are able to use qualitative analysis to identify “correct” and “incorrect” classical ballet technique, and to investigate the effect of teaching experience on this skill. The results obtained can provide important information to assist with the development of curricula and teaching programs for dance teachers.

Finally, although use of 3D motion analysis has increased in dance science research over recent years, it is not currently used as a tool for routine assessment of dance technique. Such a tool is therefore proposed as a useful method to systematically and accurately assess classical ballet technique. The final analysis section of this thesis therefore presents the methods used, results obtained and conclusions reached during development of a 3D quantitative assessment tool for evaluation of classical ballet technique.

CHAPTER 3

COMPARISON OF THEORETICAL AND PRACTICAL EXECUTION OF CLASSICAL BALLET TECHNIQUE

CHAPTER 3
COMPARISON OF THEORETICAL AND PRACTICAL EXECUTION OF CLASSICAL BALLET TECHNIQUE

3.1 Introduction

Classical ballet has been studied and performed throughout the world for many centuries. Its earliest forms were performed in the 1500s as entertainment for the nobility of the French royal courts. Over time, specific principles, guidelines and steps of the classical ballet repertoire were established. While different regions/countries have developed and established their own styles and characteristics (*e.g.* French, Russian, Italian, Danish), there are some basic principles of the classical ballet technique that have been adopted universally. As described in Chapter 2, these include principles such: as maintaining the verticality of the torso and minimising the natural curvatures of the spine during execution of ballet movements; maintaining a centred pelvic position and minimising pelvic displacement when executing movements of the lower limb; achieving maximum "turnout" (*i.e.* external rotation) of the lower limbs; and achieving maximal extension (*i.e.* knee extension and ankle plantarflexion) of the lower limbs.

Through the process of conducting the literature review, the above mentioned principles were categorised into four main fundamental principles, which have been defined as follows:

1) 'Alignment' - maintaining verticality of the torso
2) 'Placement' - minimal displacement of the pelvis from a centred position
3) 'Turnout' - maximum external rotation of the lower limbs
4) 'Extension' - maximum elongation of the lower limbs

This section of the study aims to use quantitative biomechanics techniques to investigate the level of agreement between what is considered to be theoretically correct execution of ballet technique as outlined in the dance literature, and the practical execution of classical ballet technique demonstrated by elite level ballet dancers in professional companies.

That is, the study aims to examine empirically if professional classical ballet dancers actually do execute classical ballet technique more closely to the theoretical principles outlined in the texts than non-professional dancers. To achieve this aim, a set of standard classical ballet steps will be selected for 3D motion analysis. A sample of professional ballet dancers (N=15) and a sample of non-professional ballet dancers (N=15) will be recruited. They will be asked to perform the basic classical ballet movements while undergoing full body 3D motion analysis and video analysis.

Data analysis will involve assessing the kinematic differences between the two groups of dancers in their execution of the steps. For example, thorax verticality, pelvic – thoracic rotation, pelvic tilt, pelvic obliquity, external hip rotation, knee extension, and maximum ankle plantarflexion will be compared to determine whether or not on average professional dancers execute classical ballet technique that is more like the theoretically "correct" characteristics than non-professional dancers.

It is intended that the findings of this study will inform the dance community about the level of consistency between the theoretical principles of classical ballet technique, and the practical execution of classical ballet technique as demonstrated by elite level ballet dancers in professional companies. Such information is relevant to the dance community, to ballet teachers in particular, as it will inform them of the degree to which previously established principles of ballet technique are actually executed at an elite level, and may therefore provide insight into ways in which teaching methods or instructional cues can be modified or enhanced for optimal teaching practice.

3.2 Methods

3.2.1 Participant Recruitment

Ethics approval was obtained for this study through the University of New South Wales Human Research Ethics Advisory (HREA) Panel (Appendix A). The target number of subjects for recruitment to the study was 15 non-professional ballet dancers and 15 professional ballet dancers. The sample sizes were not determined to provide a specific power, rather, the sample sizes were determined in accordance with standard practice in biomechanics (Mullineaux *et al.*, 2001), and according to the practical constraints of completing the planned program of research.

Criteria for inclusion as a non-professional ballet dancer were;

- being at least 18 years of age at the time of data collection.
- never having been employed as a ballet dancer in a professional ballet company.
- having previously passed the Royal Academy of Dance (RAD) Intermediate (formerly known as Elementary) examination, or equivalent level in an alternative syllabus.
- injury-free at time of data collection, and within the 6 months preceding the time of data collection.

For recruitment of the non-professional dancers, dancers enrolled in the University of New South Wales Bachelor of Arts (Dance)/Bachelor of Education program were provided with information about the study through their attendance at group information sessions on the university campus. During these sessions, potential participants were informed of the inclusion criteria for participation in the non-professional group, and were provided with information on what they would be required to do as study participants and how their data would be used for the study. Each potential participant was given an information and consent form during the information session.

Inclusion in the professional group was based on having achieved employment as a dancer in a professional ballet company, indicating that through the company audition process they had achieved an exemplary level of skill in classical ballet technique. Specific criteria for inclusion as a professional ballet dancer were;

- being at least 18 years of age at the time of data collection.
- employed as a dancer in a professional ballet company at the time of data collection, or within the 6 months preceding the time of data collection.
- injury-free at time of testing, and within the 6 months preceding time of testing.

The professional dancers were recruited from various professional ballet companies and classes within Australia. Methods for recruitment of professional ballet dancers included posting online advertisements on dance-related websites (*e.g.* Ausdance website), phone calls and emails to Australian dance companies (*e.g.* The Australian Ballet Company, Mod Dance Company), and through visiting a number of dance studios in the Sydney metropolitan area and speaking directly with dancers and dance teachers. Upon identifying potentially suitable subjects for the professional group, each potential participant was informed of the inclusion criteria for participation in the professional group, and was provided with information on what they would be required to do as study participants and how their data would be used for the study. Each potential participant was given an information and consent form.

Non-professional and professional dancers who were willing to participate in the study were contacted directly via email or phone to arrange the date and time of their testing sessions. One 3 hour testing session was scheduled for each participating dancer at a time of their convenience. A copy of the information and consent form was emailed to all participating subjects at the time of scheduling their testing session. All subjects provided written informed consent, in the form of a signed and dated consent form, prior to commencing any data collection for the study. All dancers were offered a pair of dance foot thongs (Bloch Foot Thong III S0675) for participation in the study.

3.2.2 Instrumentation

3.2.2.1 <u>Motion Analysis System Description</u>

3D kinematic data were collected with an 8-camera (M2Cam) motion analysis system (Vicon 612, Oxford Metrics Ltd, Oxford, UK). VICON 612 is a 3D motion measurement system comprising specialised hardware, and application software. The hardware components of the system comprise two main parts: a datastation and a workstation. The datastation contains the 8-input video converter ("vi-con"), a 64-channel analogue to digital converter, timing and control circuits, and communication ports. The cameras and analogue devices are connected to the datastation. The workstation is a personal computer running Vicon Workstation Version 5.2.4.

Vicon 612 software is divided between the datastation and workstation. A single interactive program (Vicon Workstation Version 5.2.4.) on the workstation controls system calibration, data capture, 3D data reconstruction, and display of results in the appropriate windows. The measured quantities are processed by the software, producing an output file (C3D file), which contains 3D motion data ready for further processing specific to the users requirements.

The system tracks the trajectories of a number of retro-reflective markers in the field of multiple video cameras. The video cameras emit and then detect infra-red light reflected back from the optical markers which are placed on specific anatomical locations on a subject. 3D reconstruction of optical data starts from a set of marker images in the 2D view of each camera. In order to generate 3D coordinates from 2D images the Vicon 612 system must first have reliable and accurate calibration parameters for each camera.

3.2.2.2 System Calibration.

The positions of all eight cameras were checked before each data collection session, and were repositioned, if necessary, so as to give the best possible view of all optical markers. Once all the cameras were positioned ready to perform a trial, they were calibrated to determine their exact position and orientation with respect to a laboratory set of coordinate axes. This process, known as photogrammetric calibration, was done by collecting video data from each of two "calibration reference objects", whose markers were at known 3D positions. The system was calibrated using static and dynamic calibration methods. The performance of the Vicon 612 system was dependent upon on the accuracy with which this process was conducted.

Firstly, a static calibration was conducted using an L-Frame marker device, and then a dynamic calibration was conducted using a calibration wand (240mm Space Bar Wand).

The L-Frame device, consisting of four retro-reflective markers attached at specific distances from each other (Figure 3.1), was used to determine the location and orientation of the laboratory coordinate axes and origin, and the direction of each camera relative to the axes and origin. The L-Frame was placed in the same precisely known position for the static calibration for each data collection session. Alignment plates attached to the L-Frame device enabled accurate positioning of the L-frame for each static calibration. At least 20 frames of data were captured for each static calibration with the L-Frame.

Figure 3.1 *L-Frame device for static calibration*

Following the static data capture, the L-Frame device was removed from the space and a second longer period of dynamic data was captured. To obtain this dynamic calibration data an operator moved around the entire measurement space, waving the calibration wand (Figure 3.2) on which three markers were mounted at a known separation. The accuracy of the calibration depended critically upon the distance between the two markers on the calibration wand. This distance completely determined the size of the units of distance. An error in this distance would have led to the units of distance (normally millimetres) being incorrectly scaled.

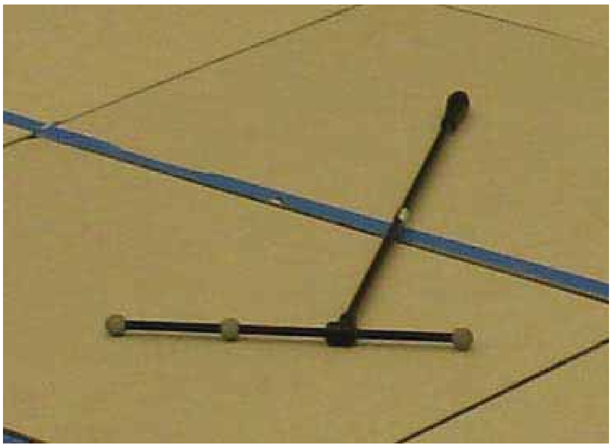


Figure 3.2 *240mm Space Bar Wand device for dynamic calibration*

At the end of the dynamic calibration, the calibration calculations were performed using an optimisation process run by Vicon Workstation software. In this process, the direction to the origin and the orientation of the vertical were determined for each camera using the static calibration data. Then, using the dynamic calibration data, calculations of increasing accuracy were made of the positions of the markers on the calibration wand, while the camera locations and orientations were also calculated with increasing accuracy, until the best fit to the data was obtained. During these calculations, the average calibration residual was updated, continually reducing with each iteration. The residual is the average distance by which each direction measurement, from the camera concerned, deviates from the location of the markers used in the calibration. Calibrations for which the residual values were below 1.3% of the reconstruction volume for each of the eight cameras were considered to be acceptable. The Vicon 612 system stored the calibration parameters for each calibration in a CP file, which was later used during the 3D reconstruction of optical data.

3.2.2.4 Marker Set

A full body marker set comprised of 38 reflective, spherical markers was used to create a 15-segment model (Figures 3.3 & 3.4). The reflective markers had a diameter of 15mm and were placed according to the Vicon Plug-in-Gait model. Markers were placed at the following anatomical sites:

- Right and left front of head (RFHD, LFHD)
- Right and left back of head (RBHD, LBHD)
- 7th cervical vertebra (C7)
- 10th thoracic vertebra (T10)
- Jugular notch between clavicles (CLAV)
- Xiphoid process of sternum (STRN)
- Right scapula (RBAK)
- Right and left acromio-clavicular joint (RSHO, LSHO)
- Right and left upper arm (RUPA, LUPA)
- Right and left lateral epicondyle of elbow (RELB, LELB)
- Right and left forearm (RFRA, LFRA)
- Right and left styloid process of radius (RWRA, LWRA)
- Right and left styloid process of ulna (RWRB, LWRB)
- Right and left head of the second metacarpal (RFIN, LFIN)
- Right and left anterior superior iliac spine (RASI, LASI)
- In-between right and left posterior superior iliac spines of sacrum (SACR)
- Right and left thigh (RTHI, LTHI)
- Right and left lateral femoral epicondyle (RKNE, LKNE)
- Right and left tibia (RTIB, LTIB)
- Right and left lateral malleolus (RANK, LANK)
- Right and left head of the second metatarsal (RTOE, LTOE)
- Right and left calcaneus (RHEE, LHEE)

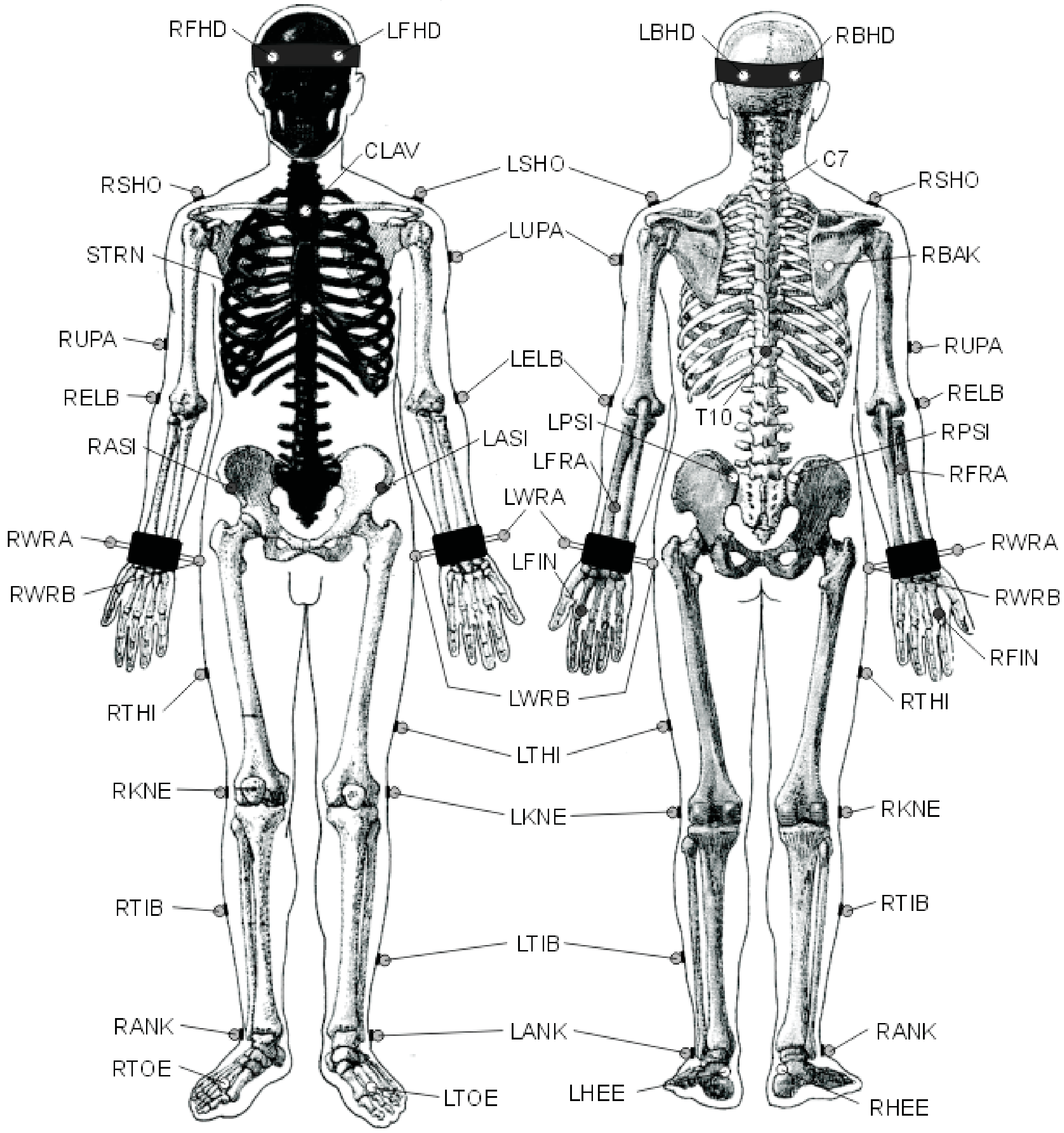


Figure 3.3 *Vicon Plug-in-Gait reflective marker placement for full body analysis (from Vicon Plug-in-Gait Manual).*

Figure 3.4 *Reflective marker placement on participant*

Knee alignment devices (KADs) were used to assist with the knee marker placement. The KAD (Figure 3.5) is a lightweight, spring-loaded G-clamp with adjustable jaws that span the knee. It was used during static trials to determine the flexion/extension axis of the knee joint, and thus to correctly place the knee markers (RKNE and LKNE). The stem is aligned with the knee flexion/extension axis, one 15mm marker is attached to the tip of this stem and two 15mm markers are attached to the ends of two additional rods fixed to the device. The three markers are exactly equidistant from the point where the stem meets the jaws of the clamp, allowing the 3D position of this point, known as the 'virtual knee marker', to be calculated. The knee markers (RKNE and LKNE) were placed directly over this point upon removal of the KADs.

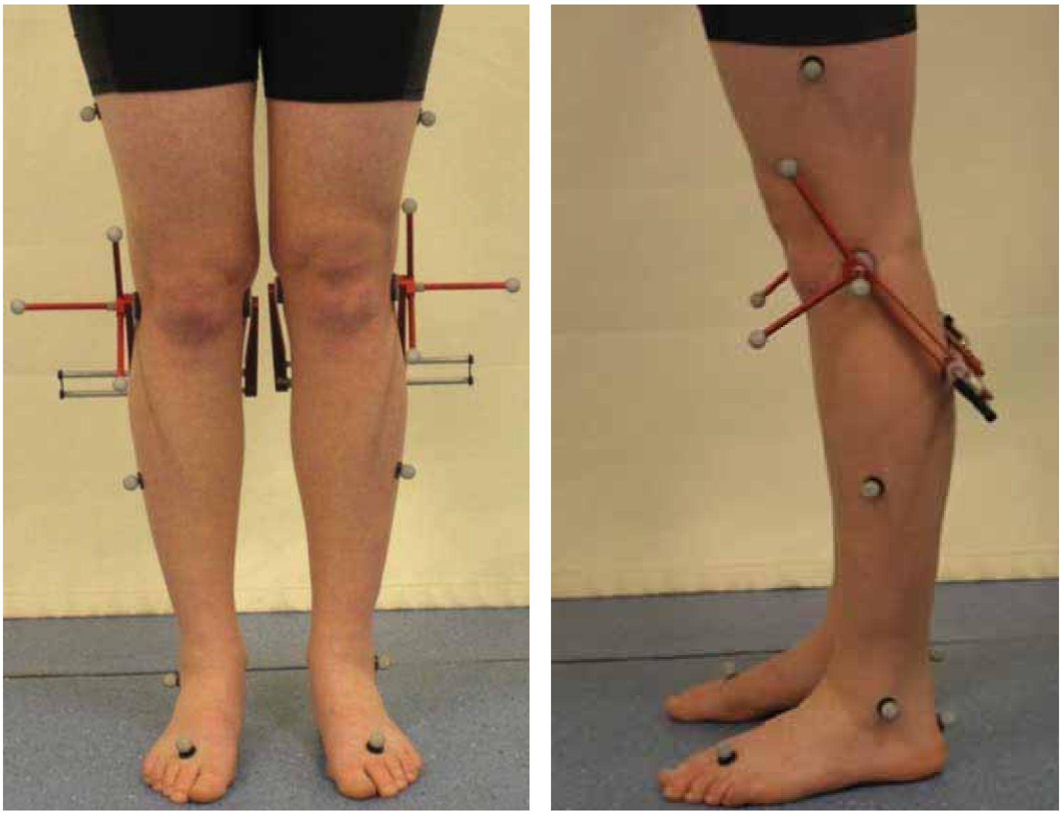


Figure 3.5 *Knee Alignment Device (KAD)*

The KAD was also used to define the alignment of the ankle flexion/extension (dorsiflexion/plantarflexion) axis. That is, during the static trial, the knee and ankle flexion/extension axes are assumed to be parallel. If for any reason this assumption is invalid, the Shank Rotation Offset can be manually reset, by entering a measurement of the subject's tibial torsion into the model. Tibial torsion was therefore measured for each subject and entered into the model for accurate calculation of the ankle flexion/extension axis. Tibial torsion was defined as the angle between the bi-malleolar axis and the knee flexion/extension axis projected onto the transverse plane (Vicon Plug-in gait Manual). It was measured according to a method commonly used in clinical practice (Staheli and Engel, 1972), whereby the patient is prone, their knee is flexed to 90°, the ankle is held neutral, a line is drawn on the sole of the foot between the malleoli, and a manual goniometer is used to measure the angle between this line and the estimated knee flexion/extension axis, assumed to be 90° to the long axis of the thigh.

3.2.2.5 Optical Data Capture and Reconstruction

All the optically derived kinematic data were sampled at 100 Hz. Kinematic data were reconstructed using Vicon Workstation software (Oxford Metrics Ltd, Oxford, UK). Reconstruction is the calculation of the 3D position of a marker and the linking of the reconstructed points in each frame into trajectories. Reconstruction was conducted according to the following process. Immediately after data capture, the Vicon Workstation software automatically saved the marker coordinate data in a TVD file, a binary file containing unprocessed data created whenever video data are captured. TVD files, together with the associated CP file obtained during system calibration, provided the input for 3D reconstruction which occurs through a process called ‘direct linear transformation’ (DLT). Reconstruction parameters were saved by Vicon Workstation in a Capture, Analogue and Reconstruction (CAR) file, the parameters of which could be edited if necessary to improve the reconstruction accuracy.

After the reconstruction, in order to uniquely identify the trajectories in the each frame, all the trajectories were labelled, according to the abbreviations specified above in Section 3.2.2.4. Once reconstruction and marker labelling was complete, the data were saved as a C3D file, a binary file created whenever video data are reconstructed, labelled and saved.

At the same time as recording 3D kinematic data, digital video data were obtained from the coronal and sagittal view for all subjects for all steps performed using two Sony digital camcorders.

3.2.2.6 Processing and Biomechanical Model

It was likely that the 3D kinematic data obtained contained imperfections that are inherent in all 3D motion capture data. Therefore, interpolation and filtering processes were applied to the data before any joint angle calculations were made. An interpolation (*i.e.* “gap filling”) procedure was conducted if gaps of up to 10 frames occurred for a single marker trajectory. This process was achieved using cubic spline curve interpolation, a form of interpolation where the interpolant is a special type of piecewise polynomial called a “spline” (Wood & Jennings, 1979; Wood, 1982). The interpolation procedure was run using the Vicon Workstation software (Additional information on the cubic spline curve interpolation is presented in Appendix E).

Since non-filtered data can appear “noisy”, all data were filtered to provide smooth and meaningful signals. Woltring's general cross-validatory (GCV) quintic spline routine (Woltring, 1985; Woltring, 1986) was used for the filtering process. The GCV filter offers the facility of selectively filtering the data signal more where it is required, and less where it is not required. The Woltring GCV filter was run using the Vicon Workstation software. (Additional information on the Woltring GCV filter is presented in Appendix F).

3D kinematic analysis of the human body is typically conducted by modelling the body as a series of rigid body segments linked at joint centres, *i.e.* locations at which the segment rotations occur. For each rigid body segment, a 3D coordinate axis system must be defined, and it is measurement of the relative movement between the 3D coordinate axis systems of neighbouring segments that facilitates calculation of joint rotation angles in each anatomical plane. A minimum of three non-collinear markers are required to establish a 3D coordinate axis system for each rigid body segment. For this study, the segment 3D coordinate axis systems and joint centre locations were defined according to the Vicon Plug-in-Gait model. The process through which the 3D coordinate axis systems were established for each rigid body segment is described in the following paragraphs.

The thorax formed a rigid segment defined by the markers on the seventh cervical vertebra (C7), the tenth thoracic vertebra (T10), the jugular notch (CLAV) and the xiphoid process of the sternum (STRN) (Figure 3.6). The 3D coordinate axis system for the thorax was defined as follows. The orientation of the thorax was defined before the origin. The first axis (Z) was defined as the line from the midpoint between the clavicle marker (CLAV) and cervical marker (C7) to the midpoint between the sternum (STRN) and thoracic markers (T10). The second axis (X) was formed between the midpoint of C7 and T10 to the midpoint of CLAV and STRN. The third axis (Y) was perpendicular to both the first (Z) and second (X) axes, and was therefore directed in the medial-lateral direction. The thorax origin was then calculated from the CLAV marker, with an offset of half a marker diameter backwards along the X axis.

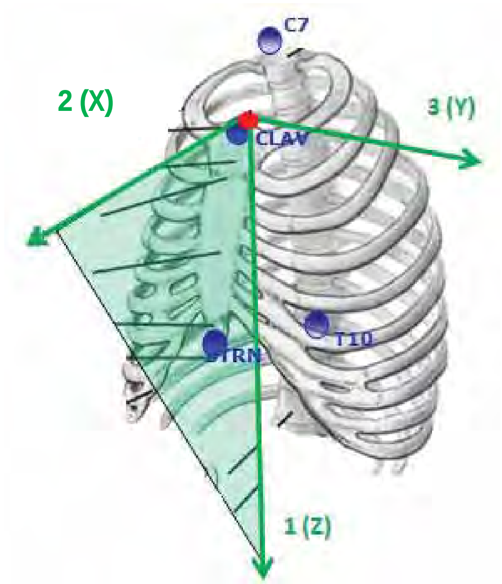


Figure 3.6 *Marker placement and three-dimensional coordinate axis system for the thorax segment. The number on each axis indicates the order in which the axes were established, the letter indicates the assigned axis direction definition (adapted from http://medical-dictionary.thefreedictionary.com and Vicon Plug-in-gait Manual).*

The pelvis formed a rigid segment created by the two anterior superior iliac spine markers (LASI, RASI) and the sacrum marker (SACR) (Figure 3.7). The origin of the pelvis segment was taken as the midpoint between the left and right ASIS markers. The first axis (Y) was the direction from the right ASIS marker (RASI) to the left ASIS (LASI) marker. The second axis (X) was taken perpendicular to the first axis in the plane formed by all three pelvis markers (LASI, RASI, SACR). The third axis (Z) was directed upwards, perpendicular to the first and second axes.

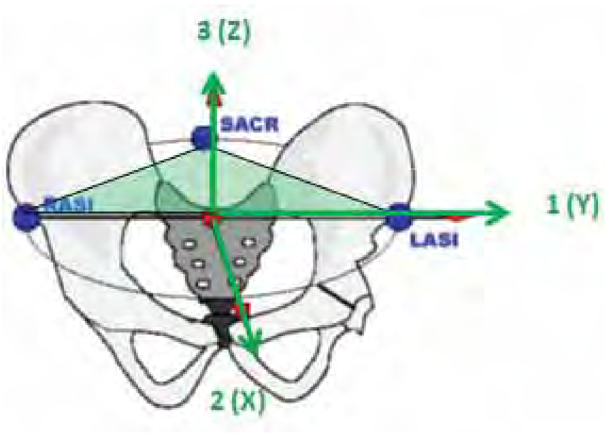


Figure 3.7 *Marker placement and three-dimensional coordinate axis system for the pelvis segment. The number on each axis indicates the order in which the axes were established, the letter indicates the assigned axis direction definition (adapted from Vicon Plug-in-Gait Manual).*

The thigh segment was defined by the hip joint centre located in the pelvis segment, the knee joint centre, the lateral thigh marker (LTHI/RTHI) and the lateral knee marker (LKNE/RKNE) (Figure 3.8). The segment origin was taken as the knee joint centre. The first axis (Z) was taken from the knee joint centre (KJC) to the hip joint centre (HJC). The second axis (Y) was taken parallel to the line from the knee joint centre to the virtual knee marker (established using the KAD). The third axis (X) for the thigh segment was perpendicular to the first and second axes.

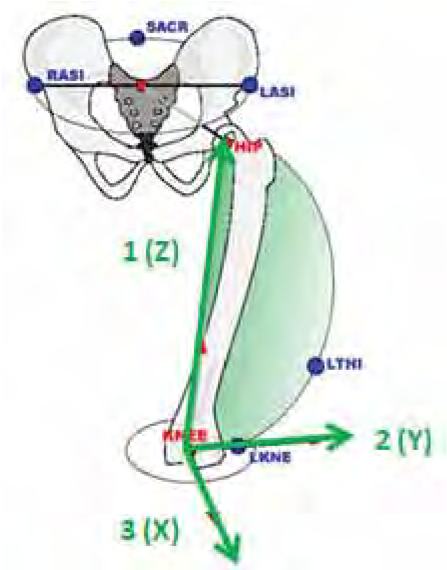


Figure 3.8 *Marker placement and three-dimensional coordinate axis system for the thigh segment. The number on each axis indicates the order in which the axes were established, the letter indicates the assigned axis direction definition (adapted from Vicon Plug-in-Gait Manual).*

The lower leg or shank segment was defined using the ankle joint centre, the knee joint centre, the lateral tibia marker (LTIB/RTIB) and the lateral ankle marker (LANK/RANK) (Figure 3.9). The first axis (Z) joined the ankle and knee joint centres. The second axis (Y) passed through the lateral ankle marker (LANK/RANK) and the ankle joint centre, which was located at a distance equal to half the ankle width plus half a marker diameter from LKNE. The first and second axes both lay in the plane formed by the knee joint centre and the markers LTIB and LANK. The third axis (X) was perpendicular to the first and second axes.

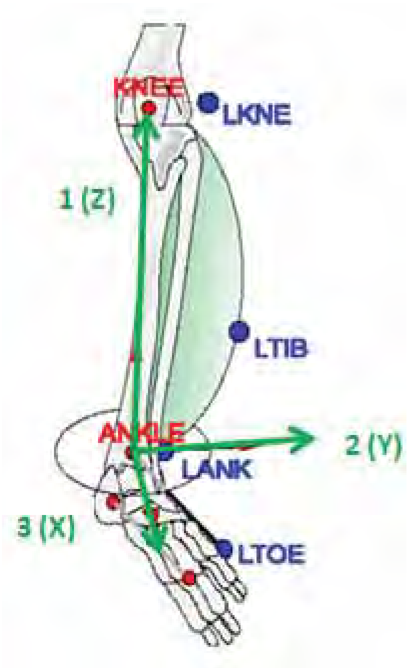


Figure 3.9 *Marker placement and three-dimensional coordinate axis system for the shank segment. The number on each axis indicates the order in which the axes were established, the letter indicates the assigned axis direction definition (adapted from Vicon Plug-in-Gait Manual).*

The foot segment was defined using the ankle joint centre, the lateral ankle marker (LANK/RANK), the toe marker (LTOE/RTOE) and the heel marker (LHEE/RHEE) (Figure 3.10). The segment coordinate system was constructed using the line joining the toe marker (TOE) and the ankle joint centre (AJC) as the first axis (Z). The direction of the second axis (Y) from the shank segment was used to define the second axis (Y) of the foot segment. The third axis (X) of the foot was perpendicular to the first and second axes.

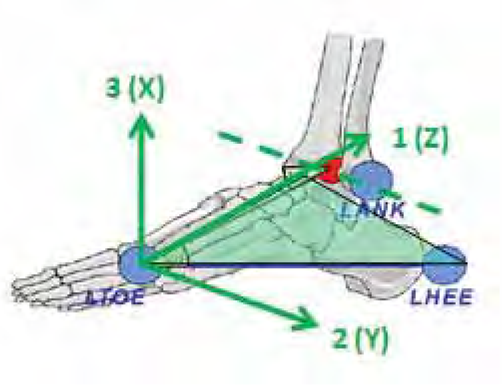


Figure 3.10 *Marker placement and three-dimensional coordinate axis system for the foot segment. The number on each axis indicates the order in which the axes were established, the letter indicates the assigned axis direction definition (adapted from Vicon Plug-in-Gait Manual).*

All joint angular displacements were calculated using the Vicon Plug-in-Gait full body model, which uses the following methods for segment and joint angle calculations. Movements of the thorax and pelvic segments were measured with respect to the global reference frame (X, Y, and Z laboratory coordinate axes established by system calibration). Sagittal plane thorax movement (forward/backward tilt) was defined as anterior/posterior movement around the Y-axis, coronal plane thorax movement (side tilt) was defined as right and left tilt around the X-axis, and transverse plane thorax rotation (forward/backward rotation) was defined as rotation around the longitudinal Z-axis.

Sagittal plane pelvic movement (anterior/posterior pelvic tilt) was defined as anterior-posterior motion around the Y-axis, coronal plane pelvic movement (pelvic obliquity) was defined as sideways movement around the X-axis, and transverse plane pelvis (forward/backward rotation) was defined as rotation around the longitudinal Z-axis.

Hip, knee, and ankle angular displacements were all calculated with respect to relative movement of the local 3D coordinate axis systems embedded within the segments. Sagittal plane hip movement (flexion/extension) was defined as anterior-posterior motion around the Y-axis, coronal plane hip movement (adduction/abduction) was defined as sideways movement around the X-axis, and transverse plane hip rotation (internal/external rotation) was defined as rotation around the longitudinal Z-axis of the thigh segment. Sagittal plane knee movement (flexion/extension) was defined as anterior-posterior motion around the Y-axis, coronal plane knee movement (valgus/varus) was defined as sideways movement around the X-axis, and transverse plane knee rotation (internal/external rotation) was defined as rotation around the longitudinal Z-axis of the shank segment. Sagittal plane ankle movement (dorsi/plantarflexion) was defined as anterior-posterior motion around the Y-axis, coronal plane ankle movement (inversion/eversion) was defined as sideways movement around the X-axis, and transverse plane ankle rotation (internal/external rotation) was defined as rotation around the longitudinal Z-axis of the foot segment.

Cardan angle conventions were used for the calculation of all joint angle rotations. Cardan angle rotations are one of the commonly used approaches to determine anatomical joint angles, and are especially relevant and useful for biomechanics applications as they can be easily used to represent the anatomical joint actions of flexion/extension, adduction/abduction, and longitudinal (internal /external) rotation. Using the Cardan angle approach, 3D joint angles are defined as a sequence of three ordered rotations from the initial position of one coordinate system. For example, a common Cardan rotation sequence used in biomechanics involves the following order of rotations.

1. Rotation about the medial-lateral directed axis
2. Rotation about the anterior-posterior directed axis
3. Rotation about the vertical/longitudinal axis

Using this order of rotations, for the segment and axis definitions employed in the current study, sagittal plane rotations (*i.e.* flexion/extension; dorsi/plantarflexion) would be calculated first about the Y-axis of the proximal segment; followed by coronal plane rotations (*i.e.* lumbar side flexion, hip adduction/abduction, knee varus/valgus and ankle inversion/eversion) about the X-axis; followed by internal/external rotation about the Z-axis (longitudinal axis) of the distal segment (Wu and Cavanagh, 1995). This sequence is equivalent to a Y, X, Z order of rotation.

It should be noted that as Cardan angles are calculated, each rotation causes the axis for the subsequent rotation to be shifted. For example, in the second rotation, the axis has already been acted upon and shifted by one previous rotation, and in the third rotation, the axis has already been acted upon and shifted by the two previous rotations.

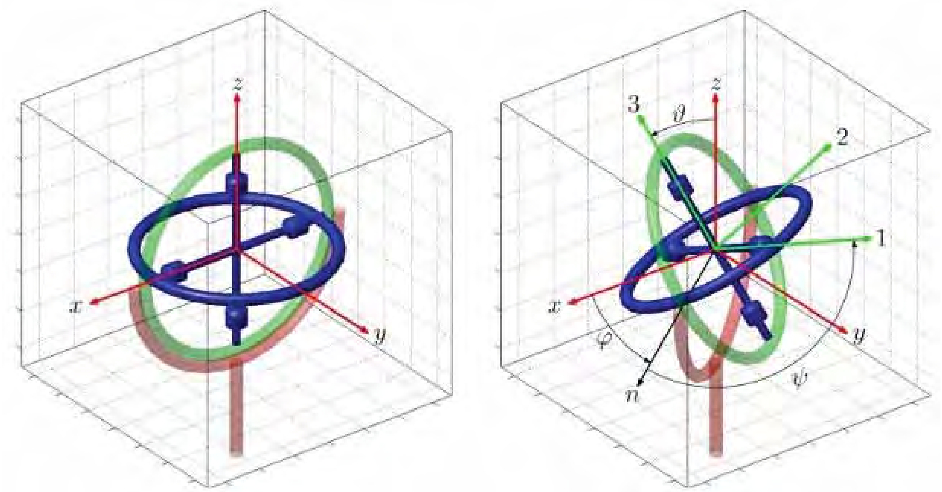


Figure 3.11 *Example of starting position (a) and end position (b) for a series of 3 Cardan angle rotations. Θ, φ, and ψ represent the resultant angles in each plane of motion at completion of all 3 rotations (from mathworks.com)*

Given this definition of Cardan angles, it would be expected that in 3D kinematic analyses, the calculated segment rotations would be highly dependent on the Cardan angle rotation sequence used (Cappozzo *et al.*, 2005). However, Lees *et al.* (2010) demonstrated that pelvic data and sagittal plane data for the hip, knee and ankle are robust with regard to the rotation sequence used. For coronal and transverse plane data for the hip, knee and ankle it was reported that the influence of rotation sequence was evident in terms of the data offset and profile (Lees *et al.*, 2010). For the hip joint, the rotation sequence influenced transverse plane data when hip flexion was greater than 50°, and for the ankle joint transverse plane data offset varied according to rotation sequence across the full range of sagittal joint motion. For these reasons, the kinematic data relating to the principle of 'turnout' will need to be interpreted with caution.

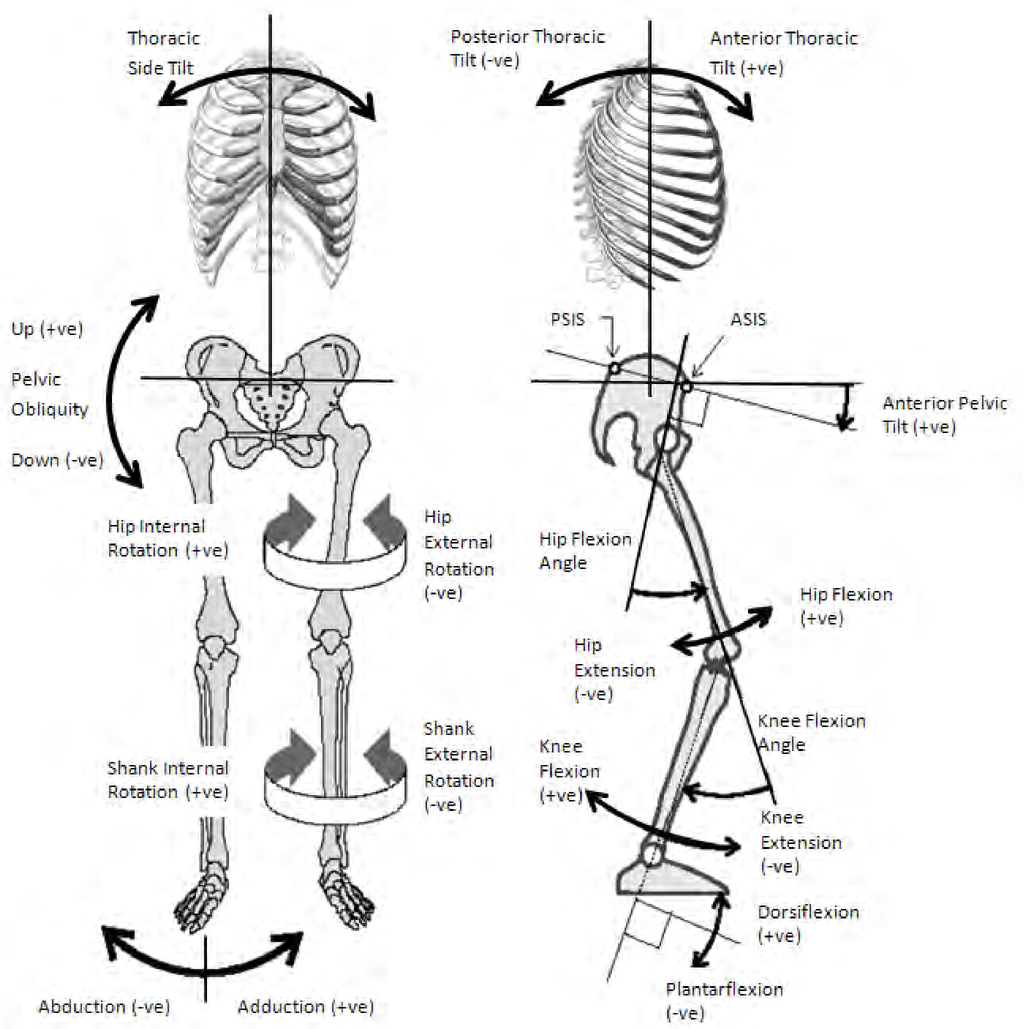


Figure 3.12 *Directions and signs for kinematic measurement variables for thorax, pelvis, hip, knee and ankle rotations (adapted from Vicon Plug-in-gait Manual).*

Figure 3.12 depicts the signs (*i.e.* positive or negative) applied to the directions of the rotations occurring in each plane at each joint for the current study. In accordance with the conventions typically used in clinical biomechanical analyses, thorax posterior tilt, lumbar spine extension, pelvic posterior tilt, hip and knee extension, and ankle plantar flexion in the sagittal plane were denoted as negative in all tables and graphs. Coronal plane movements of downward pelvic obliquity, hip abduction, knee varus, and ankle inversion, and all external rotations in the transverse plane were also denoted as negative.

It should also be noted that the kinematic model used in this study calculates 3D movement of the 'ankle joint complex' rather than that of a single anatomical joint. That is, movement occurring at this structure is due to combined motions of the talo-crural joint and the sub-talar joint. Due to the orientation of the talo-crural joint axis, the dominant movement of this joint can be considered to be dorsi/plantarflexion. However, the sub-talar joint axis lies oblique to the three anatomical planes of motion with the majority of the joint movement occurring simultaneously within the transverse and coronal planes. Consequently, the kinematic measurements obtained for the coronal and transverse plane are not directly analogous to specific anatomical joint function, but instead reflect the projection of motion of the 'ankle joint complex' into each of these planes.

3.2.3 Kinematic Measurement Variables

As described in Section 3.1, through reading a number of texts on classical ballet technique, four fundamental principles of the technique were identified. These principles were defined as:

1) 'Alignment'
2) 'Placement'
3) 'Turnout'
4) 'Extension'

In order to use quantitative techniques to analyse these principles, and determine the extent to which professional and non-professional ballet dancers adhere to these principles in their execution of classical ballet technique, it was necessary to a identify a number of biomechanical parameters that could be used as indicators of these principles. Based on the defining characteristics on which these principles are based, a collection of appropriate kinematic measurement variables were selected for analysis for the study. Each of the four fundamental principles, their defining characteristics, and their associated kinematic measurement variables are outlined in Table 3.1.

Fundamental Principle of Classical Ballet Technique	Defining Characteristics of Fundamental Principle of Classical Ballet Technique	Biomechanical Quantitative Measurement Variables
1. Alignment	Maintenance of verticality and maximum elongation of the torso	• Thoracic anterior/posterior tilt • Thoracic side tilt
2. Placement	Minimal displacement of the pelvis from its centred position	• Pelvic anterior/posterior tilt • Pelvic obliquity • Pelvic-thoracic transverse rotation
3. Turnout	Maximum external rotation of the lower limbs	• Hip external rotation • Ankle external rotation
4. Extension	Maximum elongation of the lower limbs	• Knee extension • Ankle plantarflexion

Table 3.1 *Fundamental principles of classical ballet technique and associated kinematic variables*

3.2.3.1 Potential Measurement Error

As indicated in the preceding section, for 3D biomechanical analyses, reflective markers placed on the body surface are used to define the embedded coordinate axes, and therefore the movement, of underlying bone segments. However, it is well known that error in estimation of bone segment motion exists due to movement of the markers on the surface of the body moving with respect to the underlying bones. This discrepancy between the movement of the markers and underlying bone is based on two different sources of error: anatomical landmark mislocation (*i.e.* marker placement error) and soft tissue artifact (Stagni *et al.,* 2005). Various studies have investigated the effects that marker placement error and soft tissue artefact have on the accuracy of 3D joint angle calculations.

Kadaba *et al.* (1989) conducted a repeatability study of joint angles computed from a lower limb marker set very similar to the one used in the current study, the only difference being the use of wand markers by Kadaba *et al.* (1989) to mount the sacrum and lateral thigh markers. Advances in the accuracy and resolution of motion analysis cameras since 1989 means that use of wand markers is no longer a methodological necessity, therefore in the current study these markers were attached directly to the skin. Results of Kadaba *et al.* (1989), presented as coefficient of multiple correlation (CMC), indicate that sagittal plane repeatability of hip (CMC = 0.978-0.996), knee (CMC = 0.981-0.994) and ankle joint (CMC = 0.933-0.978) data were “excellent” both within a test day as well as between test days. Repeatability for the frontal (CMC = 0.783-0.962) and transverse plane (CMC = 0.582-0.893) joint angles within-days and between-days were lower than for sagittal plane data. The fact that the current study will not use wand markers, which have a tendency to “wobble”, suggests that increased measurement reliability will be obtained in the current study compared to Kadaba *et al.* (1989). Another study by this group (Kadaba *et al.*, 1990) reported that for a 1cm variation in marker placement, a maximum constant offset of 2° in the sagittal plane angle patterns was obtained, however the ranges of joint rotations were not affected. Della Croce *et al.* (1999) also investigated the effect of marker placement error on the calculation of 3D hip, knee and ankles joint angles. Of the variables that are relevant to the current study, the precision of the intra-examiner data were 1.0°, 1.6°, 3.9° and 5.3° for knee flexion/extension, ankle dorsi/plantarflexion, ankle internal/external rotation, and hip internal/external rotation, respectively. These results from previous studies indicate that with repeated use of the same operator for reflective marker placement, excellent repeatability measures can be obtained for sagittal plane hip, knee and ankle joint angles, with slightly lower repeatability occurring for transverse plane variables. In addition, larger marker placement errors (1cm) than would be expected in the current study have been found to produce only relatively minor discrepancies in joint angle data.

Several studies have been published on the amplitude and implications of soft tissue artefact in 3D kinematic analysis. For reflective markers located on the thigh, Camomilla *et al.* (2009) obtained root mean square soft tissue displacements ranging from 2.5-23.0mm. Stagni *et al.* (2005) reported that displacement of skin markers with respect to the corresponding embedded coordinate axis system, was generally larger on the thigh segment (up to 31mm) than on the shank (up to 21 mm). In addition, as was the case for marker placement error, Stagni *et al.* (2005) also reported that coronal plane and transverse plane data were more affected by soft tissue artefact than sagittal plane data.

The increased likelihood of soft tissue displacement on the thigh, together with the higher influence of soft tissue displacement on transverse rotation data, indicates that hip transverse plane data *(i.e.* internal/external rotation) may contain multiple sources of error and should therefore be assessed with some caution.

3.2.4 Experimental Protocol

3.2.4.1 Subject Anthropometric Measurements and Marker Placement

The experiments were conducted at the University of New South Wales in the Biomechanics Laboratory in the School of Risk and Safety Sciences. Upon arrival at the laboratory, participants were familiarised with the testing environment and were informed again of what to expect and what was required of them. They were assured of the anonymity of their motion analysis data, but were reminded that by giving consent to participate in the study they were agreeing to their video data being viewed by participating dance teachers in a later part of the study. A signed and dated information and consent form (Appendices B and C) was collected from each subject at the beginning of each test session, prior to any data being collected.

Before collecting any motion analysis data, subjects were also asked to complete a questionnaire outlining their date of birth, dance training and performance history, study background, and dance injury history. This questionnaire consisted of 40 questions which were a mixture of short answer, yes/no and multiple choice questions (Appendix D). Subject height, mass, and anthropometric data were measured upon commencement of each motion analysis session. Body mass was measured using electronic scales. Anthropometric data obtained included leg length, inter anterior superior iliac spine (ASIS) distance, knee width, ankle width, shoulder anterior-posterior girth, elbow width, wrist width, foot thickness, hand thickness, and tibial torsion. During the data collection session, subjects were required to wear tight black short bike-pants, a black crop-top and foot thongs (Bloch Foot Thong III S0675).

All subjects were asked to watch a demonstration video detailing each of the dance movements that they would be required to perform during the data collection session. Non-professional and professional ballet dancers were required to perform the same steps and therefore all participants were shown the same demonstration video. Immediately after watching the demonstration video all subjects were given the opportunity to ask questions about the movement requirements and to opt out of the study if they felt that any of the movements displayed on the video could be potentially injurious to them. If willing to proceed with the test session, subjects were asked to complete a self-directed warm-up that they felt would sufficiently prepare them to perform the required steps to the best of their ability. Each dancer was allowed as much time as required for this, most dancers took 10-15 minutes to complete this process. It should be noted that no dancers opted out of the study after viewing the demonstration video.

Upon completion of their warm-up, the reflective markers were attached to the subject by palpation of the appropriate bony landmarks. Marker attachment was by way of double sided tape, and reinforcement with 3M Micropore medical tape. After attachment of all reflective markers, except the right and left knee markers (RKNE, LKNE), three static trials using the KADs were obtained. For each of these static trials the KAD was aligned in a slightly different position, with the medial side of the devise being placed in middle, anterior or posterior positions with respect to the estimated knee flexion/extension axis (estimated by visual observation and palpation of the femoral condyles). A final static trial was taken without the KADs. For this trial the right and left knee markers (RKNE, LKNE) were placed on the location of the 'virtual knee marker' as defined by use of the KADs. Anthropometric measurement, reflective marker placement and KAD application was conducted by the same operator (the author) for all subjects that participated in the study.

The first dynamic trials conducted were walking trials. Subjects were instructed to walk down the middle of the laboratory, between designated points, at a self-selected speed using their "usual" walking pattern. Six walking trials were captured for each subject. Walking trials were obtained to ensure the accuracy of the reflective marker placement. Gait cycle data were processed using the Vicon Plug-in Gait Lower Body model in Vicon Workstation (Oxford Metrics Ltd, Oxford, UK). Graphical outputs for the gait cycle data were created and displayed in Vicon Polygon Authoring Tool (see Appendix G). Given that all subjects appeared to exhibit a "normal" gait pattern, evaluation of the gait analysis graphical outputs enabled assessment of the validity of the joint displacement data. All kinematic parameters were compared to the normal data set (mean ± 1 standard deviation for normal adults) provided with Polygon Authoring Tool, but in particular, knee varus/valgus data were used as a means of assessing the accuracy of the location of the knee flexion/extension axis. The knee flexion/extension axis, along with the long axis of the femur, defines the coronal plane of the thigh segment and therefore has a strong influence on the accuracy of hip transverse rotation data.

If the knee flexion/extension axis is misplaced it can convert knee flexion movement into apparent knee varus or valgus movement (crosstalk), appearing as increased knee varus/valgus movement during the gait cycle. Knee varus/valgus range of motion (ROM) data are therefore a very useful indicator of marker placement accuracy and thus of the quality of the kinematic data. A knee varus/valgus ROM of less than or equal to 10º for the entire gait cycle was used as an indication of sufficient accuracy of the location of the knee joint flexion/extension axis, and thus sufficient accuracy of the optical marker placement. If the knee varus/valgus ROM was greater than 10º for the entire gait cycle, then the subjects static rotation offsets (obtained from processing a static trial) were adjusted by processing a different static trial that is, a static trial with a different position (middle, anterior, or posterior) of the medial side of the KAD. Upon selecting a static trial that resulted in a knee varus/valgus ROM less than or equal to 10º for the entire gait cycle, this static trial was subsequently used to process all dance movement trials.

3.2.4.2 Dance Movement Descriptions

The ballet movements the subjects were asked to perform during the data collection session were of an elementary/intermediate level and are typical of those performed in the standard classical ballet classes that all subjects would have previously experienced. Dancers were advised that if at any time during the testing session they experienced pain or discomfort, or for any other reason did not want to continue performing the dance movements, they were free to immediately cease participation and withdraw from the study. It should be noted that all participating dancers who started the data collection session completed all requirements of the experimental protocol. No dancers withdrew from the study or reported that their execution of the movements was hindered or altered in any way by pain or discomfort.

In order to ensure the consistency between dancers of the speed of execution of each step, the same musical accompaniment, played from a CD player, was used for each dancer for each type of movement performed. The music used for data collection was the same music used in the demonstration video. Dancers were reminded of *what* was required for execution of each different movement before performing it (*e.g.* sequence of movements and correct musical timing), but were given no instruction on *how* to perform each movement, that is, no technical instruction or coaching was provided at any stage throughout the testing session.

The dance movements selected for analysis were each from one of the categories of the 'Seven Movements of Dance', as defined by Jean Georges Noverre (1727 – 1810) in 1760. Noverre, one of the great ballet masters of the 18th century, has been described as the person who "laid down the scientific foundation of ballet movement" (Conyn, 1948, p7). It is commonly stated that the basic principles and categories of classical ballet movement that were outlined by Noverre have remained unaltered through the centuries and still guide every ballet dancer today. For this reason, the movement categories defined by Noverre played a pivotal role in the selection of ballet steps for analysis in this study. Noverre's 'Seven Movements of Dance' are characterised in terms of the quality of the step, and are defined as:

1. Bend (*Plié*)
2. Stretch (*Battement*)
3. Rise (*Relevé*)
4. Jump (*Sauté*)
5. Glide (*Glissé*)
6. Dart (*Elancé*)
7. Turn (*Tour*)

At least two steps from each of these seven movement categories were selected for analysis in this study. The steps are described below.

<u>*3.2.4.2.1 Movement Category 1 – Bend (Plié)*</u>

- *Step 1 – Grand Plié in First Position*
- *Step 2 - Grand Plié in Second Position*

The *grand plié* movement is a deep bend of the knees while the feet are held in one of the five positions of the feet. All subjects were asked to perform the *grand plié* movement with their feet in *first position* (Figure 3.13), and then in *second position* (Figure 3.14). The subject begins the movement with both legs straight (in either *first* or *second positions*) and with the arms held in *second position* (Figure 3.13a & Figure 3.14a), Upon commencement of the plié, the arms are lowered from *second position*, reaching *bras bas* (*i.e.* arms form an oval shape in front of the dancer with arms hanging down) by the maximum depth of the *plié* (Figure 3.13c & Figure 3.14c). The arms are then brought through *first position* while ascending from the *grand plié* (Figure 3.13d and Figure 3.14d), and then back to *second position* upon completion of the whole movement (*i.e.* on returning to straight legs) (Figure 3.13e & Figure 3.14e).

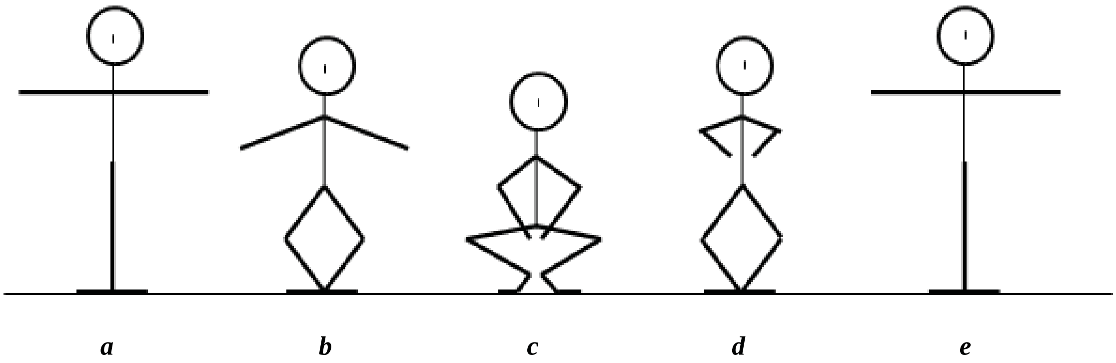


Figure 3.13 *Grand plié in first position. (a) start of plié; (b) descent of plié (c) peak of plié; (d) ascent of plié; (e) end of plié.*

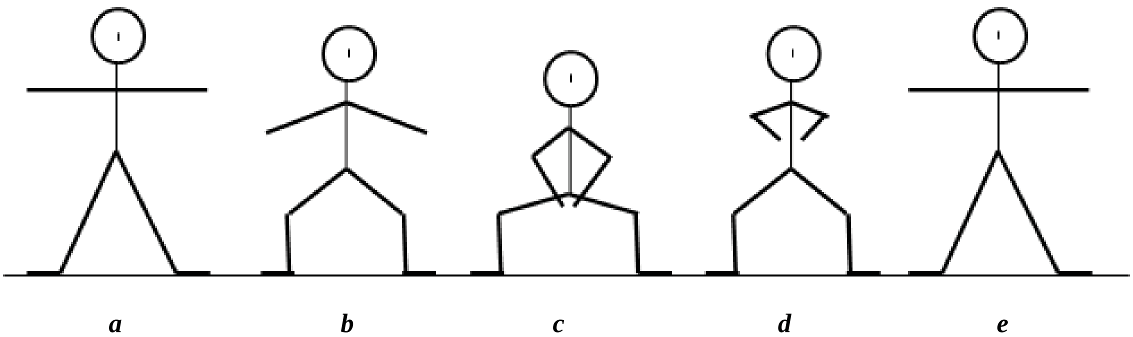


Figure 3.14 *Grand plié in second position. (a) start of plié; (b) descent of plié (c) peak of plié; (d) ascent of plié; (e) end of plié.*

<u>*3.2.4.2.2 Movement Category 2 – Stretch (Battement)*</u>

- *Step 1 - Battement Devant*
- *Step 2 - Battement Derriere*

The *battement* movement is defined as "a kicking movement of the working leg (*i.e.* the leg that is performing the movement). All subjects were asked to perform the *battement* movement to the front (*devant*) and back (*derriere*) of their body, at four different levels of leg elevation. The subject begins the movement with knees straight, with their feet in *first position* and with the arms held in *second position* (Figure 3.15a & Figure 3.16a), the arms remain in *second position* for the duration of the movement. Upon commencement of the *battement*, the subject moves their leg in one of the two directions, front (Figure 3.15) or back (Figure 3.16), while attempting to keep both knees straight. The four different levels of *battement* leg elevation performed by each subject in each of the two directions were; a *battement tendu* (kicking the working leg while keeping the toes in contact with the floor) (Figure 3.15b & Figure 3.16b), a *battement glissé* (kicking the working leg to a height just above the floor) (Figure 3.15c & Figure 3.16c), a *battement jeté* (kicking the working leg to an angle of 45° to the vertical) (Figure 3.15d and Figure 3.16d), and a *grand battement* (kicking the working leg to an angle of 90° to the vertical) (Figure 3.15e & Figure 3.16e).

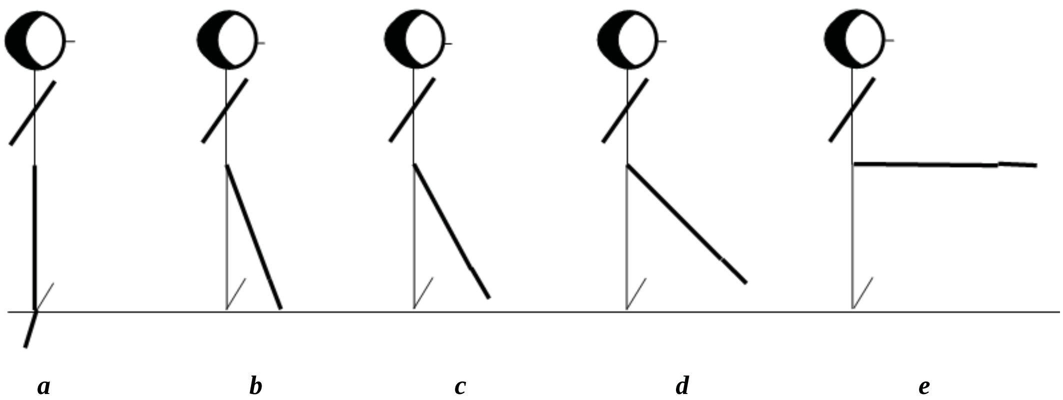
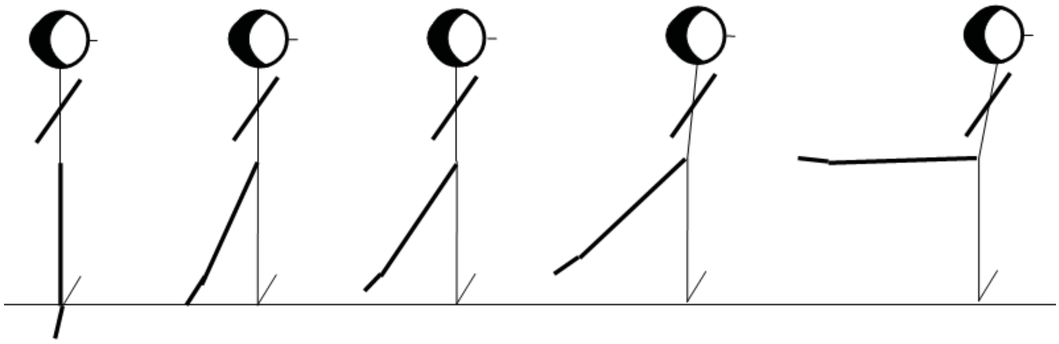


Figure 3.15 *Battement devant (front). (a) starting position for all battements devant; (b) peak position for battement tendu devant; (c) peak position for battement glissé devant; (d) peak position for battement jeté devant to 45°; (e) peak position for grand battement devant to 90°.*



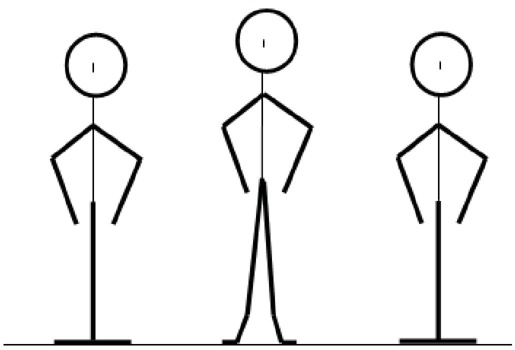
a b c d e

Figure 3.16 *Battement derriere (back). (a) starting position for all battements derriere; (b) peak position for battement tendu derriere; (c) peak position for battement glissé derriere; (d) peak position for battement jeté derriere to 45°; (e) peak position for grand battement derriere to 90°.*

3.2.4.2.3 Movement Category 3 – Rise (Relevé)

- *Step 1 - Rise in First Position*
- *Step 2 - Rise in Second Position*

The rise movement is a controlled and gradual increase in ankle plantarflexion while remaining on the balls of the feet. This movement can be performed with the feet held in any one of the five positions of the feet. All subjects were asked to perform the rise movement with their feet in *first position* (Figure 3.17), and then in *second position* (Figure 3.18). The subject begins the movement with both legs straight (in either *first* or *second positions*) and with the arms held in *bras bas* (Figure 3.17a & Figure 3.18a), the arms remain in the *bras bas* position for the entire duration of the movement. The peak of the rise movement is reached when the dancer has achieved their maximum level of ankle plantarflexion (Figure 3.17b & 3.18b), this position of the foot and ankle is referred to as *demi-pointe (i.e.* "half-point") in classical ballet terminology.



a b c

Figure 3.17 *Rise in first position. (a) start of rise; (b) peak of rise; (c) end of rise*

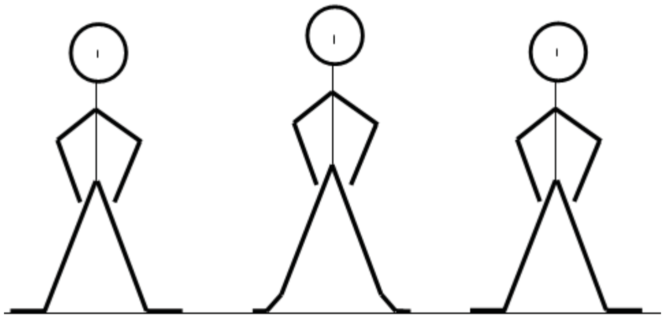
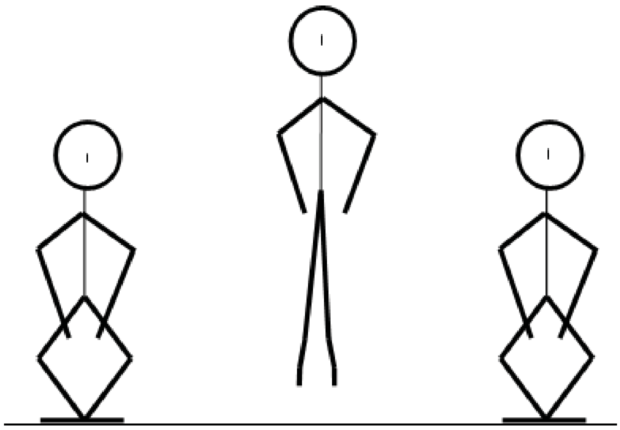


Figure 3.18 *Rise in second position. (a) start of rise; (b) peak of rise; (c) end of rise*

<u>3.2.4.2.4 Movement Category 4 – Jump (Sauté)</u>

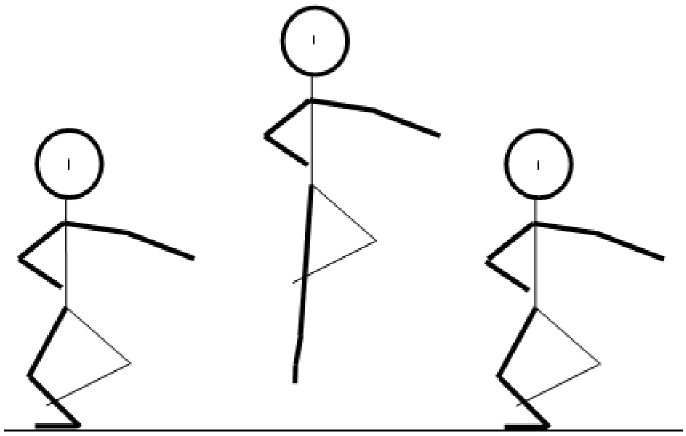
- *Step 1 - Sautè in First Position*
- *Step 2 - Temps Levè Ordinaire*

The *sauté* jump is a vertical jump with an initial countermovement (*i.e.* a preparatory bend of the knees (*demi-plié*)) to assist with the achievement of greater elevation. It is typical for this movement to be performed with the feet in either *first* or *second position*. For this study all subjects were asked to perform the *sauté* in *first position* (Figure 3.19). In the *sauté,* the dancer pushes off from two feet with both knees bent (Figure 3.19a), then while airborne the dancer must try to extend both knees and plantarflex both ankles as much as possible (Figure 3.19b). The dancer then lands back onto two feet in the same foot position from which they commenced the jump (Figure 3.19c). Arms were held in the *bras bas* position for the entire movement (Figure 3.19). In addition, the subjects were also required to perform a single leg hop, known as a *temps levé* in classical ballet terminology. All subjects performed the *temps levé* with their working leg (leg contralateral to the leg on which they were jumping) held with maximal external rotation of the hip, knee flexed to approximately 60°, and the medial side of the ankle of the working leg touching the calf of the supporting leg (Figure 3.20). Similar to the *sauté*, the *temps levé* is also performed with a countermovement (*i.e.* bend of the knees) prior the jump (Figure 3.20a), then while airborne the dancer is required to achieve maximum knee extension and plantarflexion of the supporting leg (Figure 3.20b), before landing back onto this leg with a bent supporting knee (Figure 3.20c).



a ***b*** ***c***

Figure 3.19 *Sauté in first position. (a) start of sauté; (b) peak of sauté; (c) end of sauté*



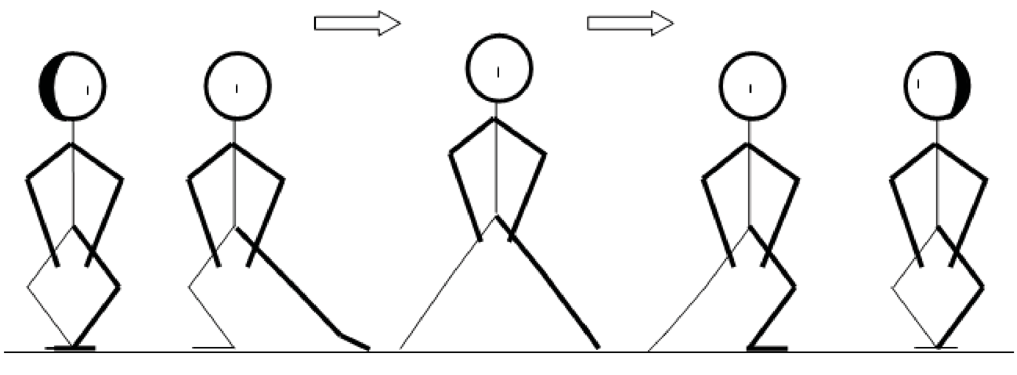
a ***b*** ***c***

Figure 3.20 *Temps levé. (a) start of temps levé; (b) peak of temps levé; (c) end of temps levé.*

3.2.4.2.5 Movement Category 5 – Glide (Glissé)

- *Step 1 - Glissade Dessus*
- *Step 2 - Glissade Dessous*

The *glissade* is a gliding travelling movement along the floor that can be performed in various directions (forwards, backwards or sideways). It is typical for this movement to be performed with the feet starting in *fifth position*. In the *glissade,* the dancer starts by bending both knees (*demi plié*) (Figure 3.21a & Figure 3.22a), then sliding the leading foot along the floor in the direction of intended movement while gradually extending the knee of the leading side until it reaches full extension (Figure 3.21b & Figure 3.22b). The dancer then pushes off the following leg, reaching a position where both knees are in full extension (Figure 3.21c & Figure 3.22c), before smoothly transferring their weight onto a bent leading leg while extending the following leg (Figure 3.21d & Figure 3.22d). The following leg then slides in to meet the leading leg in *fifth position* to complete the movement (Figure 3.21e & Figure 3.22e). Various forms of the *glissade* movement exist, they are categorised according to the direction of travel, forward (*en avants*), backwards (*en arriere*), and sideways (*de cote*). *Glissade de cote* can be further categorised according to which foot leads the movement, front foot (*devants*) or back foot (*derriere*), and whether or not the feet change position during the movement. When the front foot leads the movement and changes to the back by the end of the movement the step is called *glissade* under (*dessous*) (Figure 3.21), when the back foot leads the movement and changes to the front by the end of the movement the step is called *glissade* over (*dessus*) (Figure 3.22). For this study, all subjects were asked to perform four consecutive *glissades de cote,* in the sequence of "under, over, under, over" ("*dessus, dessous, dessus, dessous").* All subjects performed the *glissades dessus and dessous* starting with their feet in *fifth position*. Subjects were asked to hold their arms in the *bras bas* position for the duration of the movement sequence. The 2nd (*dessus*) and 3rd (*dessous*) glissades of the sequence were selected for analysis.



a ***b*** ***c*** ***d*** ***e***

Figure 3.21 *Glissade dessous (under). (a) starting position for glissade; (b) push-off from following leg; (c) peak of glissade; (d) weight transference onto leading leg (e) ending position for glissade.*

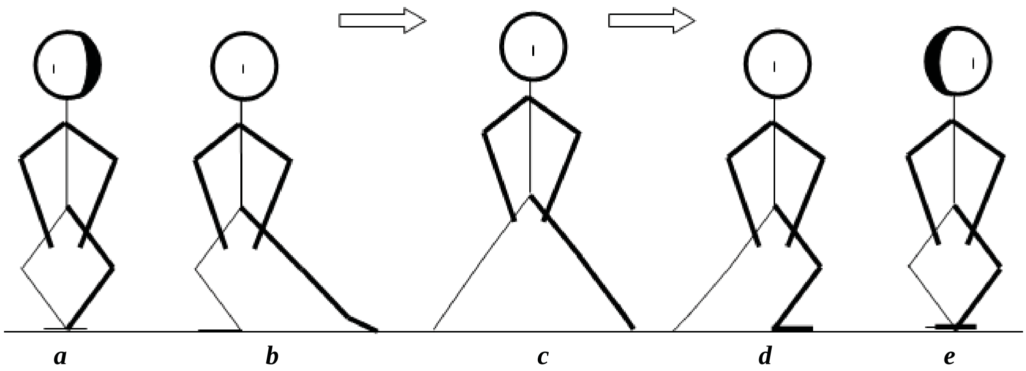


Figure 3.22 *Glissade dessus (over). (a) starting position for glissade; (b) push-off from following leg; (c) peak of glissade; (d) weight transference onto leading leg (e) ending position for glissade.*

3.2.4.2.6 Movement Category 6 – Throw or dart (Elancé)

- *Step 1 - Jeté Ordinaire*
- *Step 2 - Grand Jeté Elancé en Avants*

An *elancé* movement requires the dancer to make a strong push away from, but also just over, the floor (Lawson, 1979). The *jeté* movement possesses the *elancé* quality and was considered to be a suitable step for analysis. "*Jeté*" is a generic term used for numerous jumping steps whereby the dancer jumps from one leg to the other while one leg is "thrown" outward in the process of execution (Lee, 1983). For this study, all subjects were asked to perform a *jeté ordinaire derriere* (Figure 3.23) and a *grand jeté elancé en avants* (Figure 3.23). For the *jeté ordinaire derriere*, the dancer starts with their feet in *fifth position* (Figure 3.23a). Upon commencing the movement the back leg is thrust out towards the side of the body, while the knee is straightened to full extension (Figure 3.23b). As the leg is thrust out the knee of the other leg (the supporting leg) bends (*demi-plié*) and then the dancer push forcefully off the supporting leg jumping into the air (Figure 3.23c). The dancer lands back on the floor onto the leg that was initially thrust out (Figure 3.23d).

The *grand jeté elancé en avants* movement (Figure 3.24) is also a throwing jumping movement in which the dancer pushes off one leg and lands on the other. It is essentially a leap from one leg (Figure 3.24a) to the other during which the dancer tries to travel as far as possible in the forward direction, while splitting their legs to their maximum ability at the peak of the movement. At the peak of the *jeté*, the dancer should have their leading hip flexed as much as possible in front of their body with their knee at full extension, while their back leg is simultaneously extended as much as possible behind their body, also with the knee in full extension (Figure 3.24b).

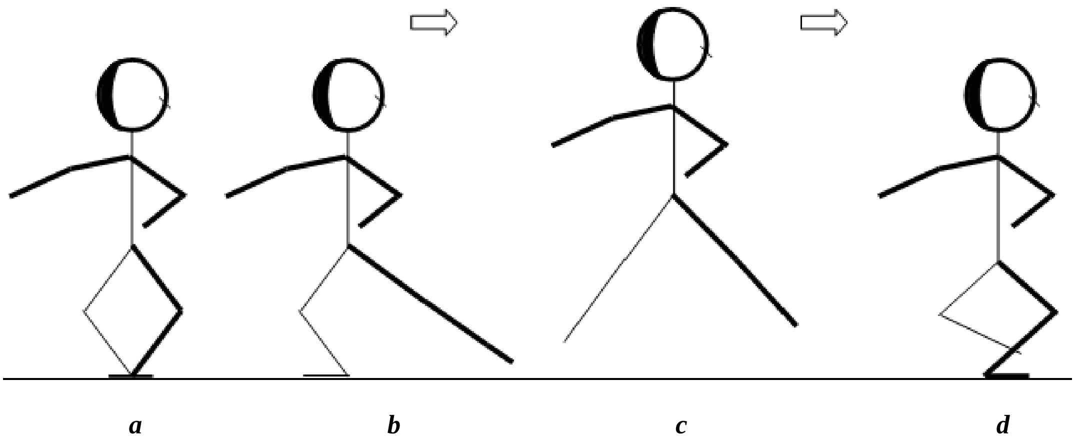


Figure 3.23 *Jeté ordinaire. (a) starting position for jeté ordinaire; (b) push-off from following leg; (c) peak of jeté ordinaire.; (d) ending position for jeté ordinaire.*

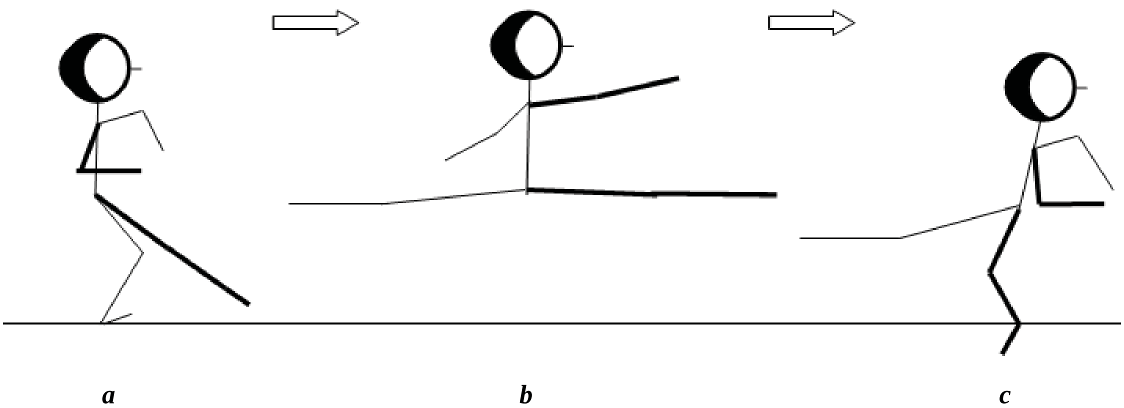


Figure 3.24 *Grand jeté elancé en avants. (a) push-off position for grand jeté; (b) peak of jeté grand jeté; (d) ending position for grand jeté.*

3.2.4.2.7 Movement Category 7 – Turn (Tour)

- *Step 1 – Double Pirouette En Dehors*
- *Step 2 - Double Pirouette En Dedans*

The *pirouette* is a turning movement in which the dancer spins on the spot while standing on one leg with the heel raised to so that the base of support consists only of the ball of the foot (Figure 3.25 & Figure 3.26). The “supporting” leg on which the dancer stands must be as extended as possible (*i.e.* maximum knee extension and maximum ankle plantarflexion) for the duration of the movement. The other leg, the “working leg” is held in a *retiré* position for the duration of the movement. For correct execution of the *retiré* position, the working knee is flexed such that the toe of the working leg is placed at knee height of the supporting leg. The working ankle should be held in maximum plantarflexion, and the working and supporting hips should both be held in maximum external rotation for the duration of the movement (Figure 3.25b & c, Figure 3.26c & d). For this study all subjects were asked to perform two different versions of the double *pirouette,* a double *pirouette en dehors* (Figure 3.25) and a double *pirouette en dedans* (Figure 3.26). Both these movements are performed with the supporting and working legs placed in the positions described above, however the difference between these two steps is the direction in which the dancer spins. For the double *pirouette en dehors* the dancer performs two complete revolutions spinning towards the direction of the working leg, while for the double *pirouette en dedans,* the dancer performs two complete revolutions spinning towards the direction of the supporting leg. For both these movements the subjects were asked to initiate the *pirouette* with their feet in *fourth position,* and their arms in *third position* (Figure 3.25a and Figure 3.26a). Subjects were asked to hold their arms in *first position* for the duration of each version of the double *pirouette* (Figure 3.25b & c, Figure 3.26c & d).

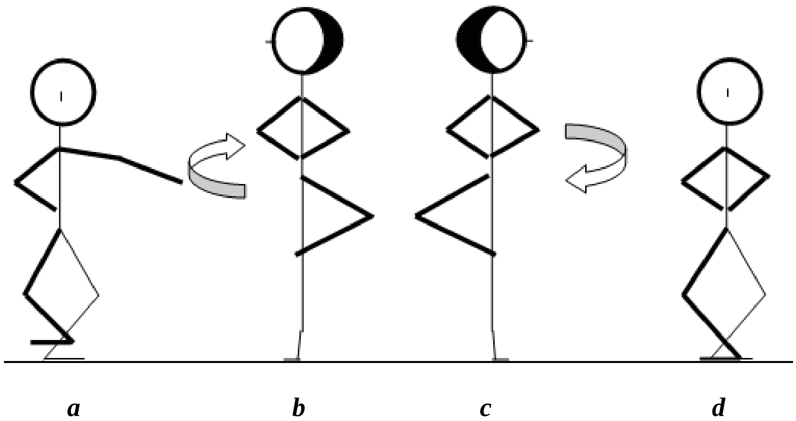
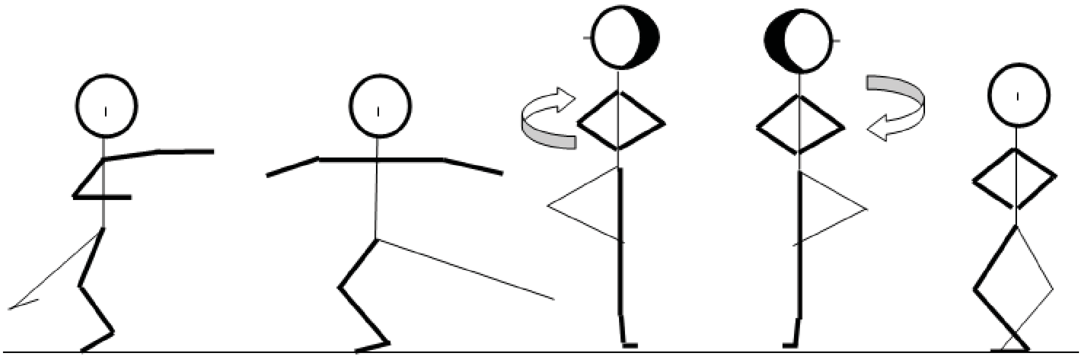


Figure 3.25 *Pirouette en dehors. (a) preparatory position for pirouette; (b) start of pirouette; (c) end of pirouette; (d) finishing position for pirouette*



a *b* *c* *d* *e*

Figure 3.26 *Pirouette en dedans. (a) preparatory position for pirouette; (b) initiating movement for pirouette (i.e. fouette movement) (c)start of pirouette; (d) end of pirouette; (d) finishing position for pirouette.*

3.2.5 Data Extraction

After calculation of the kinematic variables, each trial was exported from Vicon Workstation and saved as an ASCI file. In order to analyse the kinematic data and make comparisons between groups, it was necessary to identify specific time points within each trial that corresponded with the start, peak and end of each movement. This was achieved through the use of Visual Basic code. For each movement category, specific criteria were established according to which the relevant time points were identified. A different Visual Basic macro was written by the author for each different category of movement. The criteria used for identification of the relevant time points for each movement category are described below.

3.2.5.1 Movement Category 1 – Bend (Plié)

Plié commencement (0% of the movement) (Figure 3.13a & Figure 3.14a) was defined as the instant of the first of three consecutive increases in knee flexion (Knee-X) of at least 2%. The peak of the *grand plié* (Figure 3.13b & Figure 3.14b), the instant of maximum depth of the *grand plié,* was defined as the point at which maximum knee flexion (maximum Knee-X) was achieved The end of the *grand plié* (100% of the movement) was defined as the instant of the last of three consecutive decrease in knee flexion (Knee-X) of less than 2%.

3.2.5.2 *Movement Category 2 – Stretch (Battement)*

The sagittal plane thigh angle variable was used to identify significant time points for battements towards the front (*devant*), or back (*derriere*) of the body. Specifically, for *battements devant*, *battement* commencement (0% of the movement) (Figure 3.15a) was defined as the first of three consecutive increases of at least 2% in sagittal plane thigh angle. The peak of the *battement devant* (Figures 3.15b, 3.15c, 3.15d, 3.15e), the instant of maximum height of the *battement devant,* was defined as the point at which maximum sagittal plane thigh angle was achieved. The end of the *battements devant* (100% of the movement) (Figure 3.15a) was defined as the last of three consecutive decreases of less than 2% in sagittal plane thigh angle.

For *battements derriere, battement* commencement (0% of the movement) (Figure 3.16a) was defined as the first of three consecutive decreases of at least 2% in sagittal plane thigh angle. The peak of the *battements derriere,* (Figures 3.16b, 3.16c, 3.16d, 3.16e), the instant of maximum height of the *battement derriere,* was defined as the point at which minimum sagittal plane thigh angle was achieved. The end of the *battements derriere* (100% of the movement) (Figure 3.16a) was defined as the last of three consecutive increases of less than 2% in sagittal plane thigh angle.

3.2.5.3 *Movement Category 3 – Rise (Relevé)*

Rise commencement (0% of the movement) (Figure 3.17a & Figure 3.18a) was defined as the first of three consecutive increases of at least 2% in ankle plantarflexion (*i.e.* three consecutive decreases in Ankle-X) The peak of the rise (Figure 3.17b & Figure 3.18b), instant of maximum height of the rise, was defined as the point at which maximum plantarflexion (*i.e.* minimum Ankle-X) was achieved. The end of the rise (100% of the movement) (Figure 3.17c & Figure 3.18c) was defined as the last of three consecutive decreases of less than 2% in ankle plantarflexion (*i.e.* three consecutive increases in Ankle-X).

3.2.5.4 *Movement Category 4 – Jump (Sauté)*

Jump commencement (0% of the movement) (Figure 3.19a & Figure 3.20a) was defined as the point at which maximum knee flexion (*i.e.* maximum Knee-X) was achieved. The peak of the jump (Figure 3.19b & Figure 3.20b), the instant of maximum height of the jump, was defined as the point at which maximum vertical displacement of the whole body was achieved (*i.e.* maximum COM-Z). The end of the jump (100% of the movement) (Figure 3.19c & Figure 3.20c) was defined as the point at which maximum knee flexion (*i.e.* maximum Knee-X) was achieved again.

3.2.5.5 <u>*Movement Category 5 – Glide (Glissé)*</u>

Glissade commencement (0% of the movement) (Figure 3.21a & Figure 3.22a) was defined as the point at which maximum knee flexion (*i.e.* maximum Knee-X) was achieved on the leading leg at the beginning of the movement. The peak of the *glissade* (Figure 3.21c & Figure 3.22c) was defined as the point at which maximum vertical displacement of the whole body was achieved (*i.e.* maximum COM-Z). The end of the *glissade* (100% of the movement) (Figure 3.21e & Figure 3.22e) was defined as the point at which maximum knee flexion (*i.e.* maximum Knee-X) was achieved on the following leg.

3.2.5.6 <u>*Movement Category 6 – Throw or dart (Elancé)*</u>

For both the *jeté ordinaire derriere* and the *grand jeté elancé en avants* commencement (0% of the movement) (Figure 3.23b & Figure 3.24a) was defined as the point at which maximum knee flexion (*i.e.* maximum Knee-X) was achieved on the supporting (push-off) leg at the beginning of the movement. The peak of the *jeté* (Figure 3.23c & Figure 3.24b) was defined as the point at which maximum vertical displacement of the whole body was achieved (*i.e.* maximum COM-Z). The end of the movement (100% of the movement) (Figure 3.23d & Figure 3.24c) was defined as the point at which maximum knee flexion (*i.e.* maximum Knee-X) was achieved on the leading/landing leg.

3.2.5.7 <u>*Movement Category 7 – Turn (Tour)*</u>

For the turning steps (*pirouettes*), Visual Basic code was written to identify four rather than three time points in each trial. These were the points at which the subject commenced the *pirouette*, reached the *pirouette retiré* position, finished the *pirouette retiré* position, and then placed their working foot back on the ground again. For both the *pirouette en dehors* and the *pirouette en dedans* commencement (0% of the movement) (Figure 3.25a & Figure 3.26a) was defined as the point at which the working foot left the ground. This time point was defined as the first of three consecutive increases of at least

2% in the ankle marker vertical displacement, (*i.e.* the first of three consecutive increases in LANK-Z or RANK-Z). The instant of reaching the *pirouette retiré* position (Figure 3.25b & Figure 3.26c) was defined as the last of three consecutive increases of at least 2% in knee flexion (*i.e.* Knee-X). The instant of finishing the *pirouette retiré* position (Figure 3.25c & Figure 3.26d) was defined as the first of three consecutive decreases of at least 2% in knee flexion (*i.e.* Knee-X). The end of the pirouette (100% of the movement) (Figure 3.25d & Figure 3.26e) was defined as the last of three consecutive decreases of less than 2% in the ankle marker vertical displacement, (*i.e.* the last of three consecutive decreases in LANK-Z or RANK-Z). The instances of the movement 'start' and 'peak' used for the inter-group analysis were the instant of reaching the *pirouette retiré* position and the instant of finishing the *pirouette retire*, respectively.

For comparison of kinematic data between the non-professional and professional groups, the relevant kinematic measurement variables at the start and peak of each step for each subject were extracted and tabulated using a Visual Basic macro written by the author.

3.2.6 Statistical Analysis

SPSS™ version 18.0 software was used for all statistical analysis. Descriptive statistics for all relevant kinematic measurement variables at the start and peak of each step were calculated for each group.

Independent-samples t-tests were used to make comparison between groups of some of the specific kinematic variables used for identification of the start and peak of time points for each step in each movement category. That is, to ensure the validity of making comparisons between groups in all the kinematic variables that relate to the four fundamental principles of classical ballet technique (listed in Table 3.1), it was important to check the level of consistency or similarity between groups in the time point defining variables at each time point. This was particularly important for the *battement* steps. That is, as mentioned in Section 3.2.5.1, the start and peak time points for the *battements* (kicks) to the front (*devant*) and back (*derriere*) of the body were identified according to global sagittal plane thigh angle data, (*i.e.* thigh elevation). During the data collection sessions, participants were instructed to kick their legs to specific degrees of elevation for each different *battement* step, so that comparison of the nine kinematic measurement variables could be made at a consistent ‘peak’ of the movement. The elevation of the thigh could have a direct effect on the position of the thorax and pelvis, the external rotation of the hip, and the extension of the knee (*i.e.* the kinematic variables associated with the fundamental principles of classical ballet), it was therefore important to ensure that kinematic variables were being compared at similar levels of thigh elevation at the peak of the *battement* movements. Based on these analyses, only two *battement* steps were selected for inclusion in future analyses.

After identification of the *battements* for which there was adequate consistency between groups in the time point defining variables, independent-samples t-tests were conducted to test for significant differences between groups at the start and peak of each step in the nine kinematic measurement variables. Each step included in this analysis was investigated with respect to the four fundamental principles of ‘alignment’, ‘placement’, ‘turnout’ and ‘extension’. Because repeated measures of the same variable were made for each participant, *e.g.* each parameter was measured for each participant performing multiple steps, a repeated measures general linear model analysis was conducted for each variable to adjust for multiple comparisons. Within-subject factors used in this analysis were “step”, and “time point”, and the between-subject factor was “group”. For all statistical analyses, results were considered to be significant if a p-value of less than 0.05 was obtained.

3.3 Results

3.3.1 Subject Demographics

Within the time available for completion of the study, twenty-six healthy female adult ballet dancers volunteered to participate. Fourteen participants satisfied the criteria for inclusion in the non-professional group, and twelve participants satisfied the criteria for inclusion in the professional group. The non-professional dancers were all students enrolled in the University of New South Wales Bachelor of Arts (Dance)/Bachelor of Education program. The professional dancers were recruited from various professional ballet companies and classes within Australia.

Professional ballet dancers were older (24.7 ± 4.4 years) than the non-professional dancers (19.6 ± 2.0 years). There was no significant difference in the mean total years of ballet training between groups, however the professional group had a mean duration of full-time (vocational) ballet training of 4.1± 2.0 years, while none of the non-professional dancers had received any full-time training in classical ballet throughout their dance training history. There were no statistically significant differences between groups in mean height or mass, however there was a difference in body mass index (BMI). The lower mean BMI (19.6±1.3) recorded for the professional dancers is consistent with the slender body aesthetic typically required for success as a professional ballet dancer.

Group	Non-professional	Professional
Age (years)	19.6 ± 2.0	24.7 ± 4.4*
Height (cm)	163.7 ± 6.6	165.4 ± 4.2
Mass (kg)	57.7 ± 7.2	53.7 ± 4.7
Body Mass Index (BMI)**	21.5 ± 2.0	19.6 ± 1.3*
Total years ballet training	11.6 ± 4.3	14.3 ± 4.3
Years full-time (vocational) ballet training	0.0 ± 0.0	4.1 ± 2.0*

Table 3.2: *Participant demographics (Mean ± SD)*
**t-test ($p<0.05$): Age, BMI, and Years full-time ballet training.*
*** BMI = mass(kg)/(height(m))^2*

3.3.2 Comparison of Variables Used to Define Start and Peak Time Points for Battements

All dancers were instructed to perform multiple *battement* movements at varying degrees of thigh elevation. Despite being given specific instructions, it was important to ensure that, on average, both groups of dancers performed the *battements* subsequently selected for analysis to a statistically similar height, thereby ensuring that valid comparisons between groups could be made. Table 3.3 shows the results of the independent-samples t-tests for the time point (start and peak) defining variables for the *battement* steps.

Step	Time point	Time Point Defining Variable	Mean Difference (Non-professional – Professional)	p value (2-tailed t-test)	Std. Error Difference	95% Confidence Interval of the Difference	
						Lower	Upper
Battement Tendu Front	Start	Global Thigh Sagittal Angle	2.762°*	0.003	0.836	1.032	4.492
	Peak	Global Thigh Sagittal Angle	-1.190°	0.274	1.062	-3.389	1.008
Battement Glissé Front	Start	Global Thigh Sagittal Angle	2.024°*	0.026	0.854	0.261	3.787
	Peak	Global Thigh Sagittal Angle	-3.702°	0.143	2.432	-8.765	1.360
Battement Jeté 45° Front	Start	Global Thigh Sagittal Angle	2.833°*	0.036	1.274	0.200	5.467
	Peak	Global Thigh Sagittal Angle	-5.440°	0.193	4.061	-13.842	2.961
Grand Battement 90° Front	Start	Global Thigh Sagittal Angle	2.690°	0.043	1.240	0.091	5.290
	Peak	Global Thigh Sagittal Angle	-11.488°*	0.001	2.981	-17.691	-5.286
Battement Tendu Back	Start	Global Thigh Sagittal Angle	1.179°	0.295	1.095	-1.112	3.469
	Peak	Global Thigh Sagittal Angle	1.071°	0.225	0.852	-0.722	2.865
Battement Glissé Back	Start	Global Thigh Sagittal Angle	1.083°	0.290	0.999	-0.985	3.152
	Peak	Global Thigh Sagittal Angle	4.298°*	0.048	2.069	-0.031	8.626
Battement Jeté 45° Back	Start	Global Thigh Sagittal Angle	1.607°	0.150	1.081	-.626	3.841
	Peak	Global Thigh Sagittal Angle	5.845°*	0.037	2.647	0.380	11.310
Grand Battement 90° Back	Start	Global Thigh Sagittal Angle	0.690°	0.518	1.503	-1.485	2.866
	Peak	Global Thigh Sagittal Angle	11.786°*	0.000	2.048	7.465	16.106

Table 3.3 *Results of the independent-samples t-tests for global thigh sagittal angle (thigh elevation) at the start and peak of the battement movements. *t-test (p<0.05)*

For the *battements devant* (kicks forwards), the *battement jeté* to 45° was the highest *battement* for which there was not a statistically significant difference between groups in mean global thigh sagittal angle (thigh elevation) at the peak of the step. For this reason, the *battement jeté* to 45° was chosen for further analysis. For the *battements derriere* (kicks backwards), a statistically significant difference between groups in mean sagittal thigh elevation at the peak of the step was obtained for all steps except the *battement tendu derriere* (kick backward along the floor), therefore this step was selected as the *battements derriere* step that would undergo further analysis. Thus, the *battement jeté devant* to 45° and *battement tendu devant* were the two steps chosen to represent the *battement* movement category.

Fourteen steps, two from each movement category, were included in the between group analysis of the nine kinematic measurement variables that represent the fundamental principles of classical ballet technique. These inter-group comparisons are presented in the next section.

3.3.3 Between Group Analysis of Fundamental Principles with Respect to Joint and Segment Kinematics

Results for the comparison of kinematic variables between the non-professional and professional groups will be presented with respect to the four fundamental principles of classical ballet technique that have been identified by literature review. Group means for each of the nine kinematic measurement variables selected as indicators of the four fundamental principles, and results for independent-samples t-tests between group means, are presented in Figures 3.27 – 3.44. Significant differences between group means are indicated by asterisks (*). Descriptive statistics (means, standard deviations, and p-values) for each of the nine kinematic measurement variables are presented in Appendix H. Results of the general linear model analyses are presented in Tables 3.4 – 3.15.

It should be noted that although all participants completed all steps during the data collection sessions, there is some variability between kinematic variables in the sample sizes presented in the results. This is because for some travelling steps (*i.e.* some *jetés* and *glissades*) the subjects were on the edge of the capture volume as the step commenced and it was therefore not possible to resolve all marker placements for all participants at this time point. Since the general linear model includes data from multiple steps, a reduction in data points for one step will decrease the resulting sample size for the whole analysis.

3.3.3.1 Alignment

The principle of alignment relates to the orientation and shape of the upper body. Specifically, this principle is defined by the characteristics of maintaining the verticality of the thorax and minimising the natural curvatures of the spine during execution of ballet movements. The kinematic measurement variables selected as biomechanical indicators of this principle are thorax anterior/posterior tilt and thorax side tilt. Group means for these parameters at the start and peak of each step, and results for independent-samples t-tests between group means are presented in Figures 3.27 - 3.30 Results of the repeated measures general linear model analysis, conducted to adjust for multiple comparisons, are presented in Table 3.4 and Table 3.5.

3.3.3.1.1 Thorax Anterior/Posterior Tilt

Figures 3.27 and 3.28 indicate that for most steps and time points, non-professional and professional dancers held their torso in a position of posterior thoracic tilt. Significant differences between groups in thorax anterior/posterior tilt were only obtained for the start and peak of the *grand plié in first position*, the start of the *grand plié in second position*, and the peak of the *temps levé*. There is no observable trend when comparing mean thorax anterior/posterior tilt between groups at the start of each step. That is, greater mean thorax posterior tilt was demonstrated by the professionals for half of the steps, with this relationship being reversed for the other half of steps. Greater posterior thoracic tilt was demonstrated by the professionals at 71% of step peaks (10 out of 14), however statistical significance was only achieved for two of these steps.

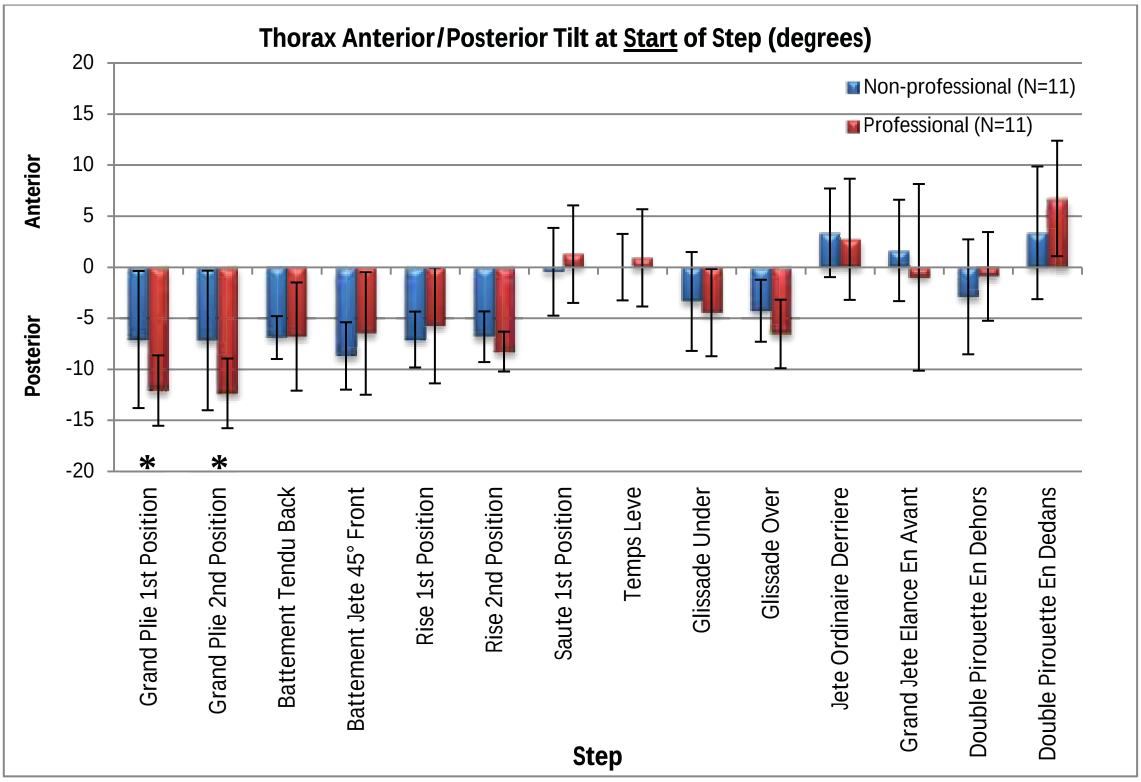


Figure 3.27 *Thorax anterior/posterior tilt at start of step.*
** Significant difference between groups (t-test: p<0.05). Error bars = ± 1 standard deviation*

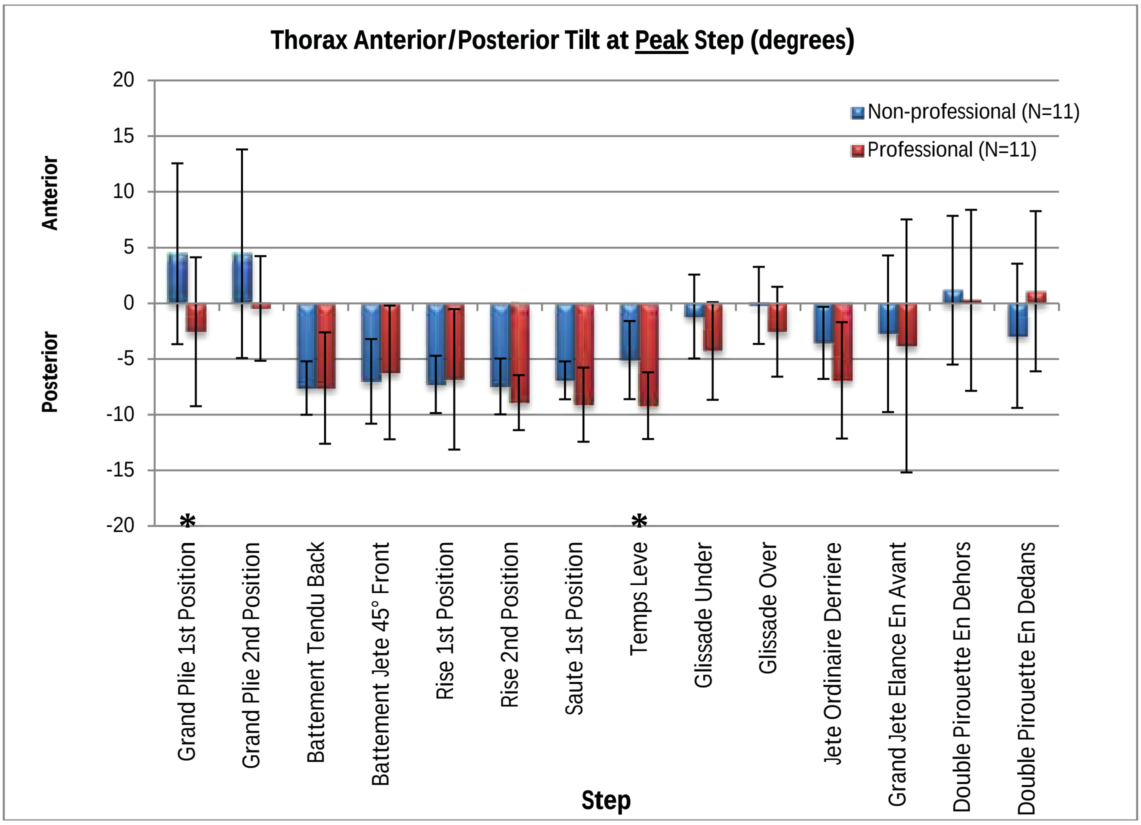


Figure 3.28 *Thorax anterior/posterior tilt at peak of step.*
** Significant difference between groups (t-test: p<0.05). Error bars = ± 1 standard deviation*

Time point	Mean Difference (°) (Non-professional - Professional)	Standard Error	p-value[a]	95% Confidence Interval for Difference[a]	
				Lower Bound	Upper Bound
Start	-0.468	0.808	0.569	-2.153	1.218
Peak	-1.313	0.937	0.175	-3.252	0.627
Start & Peak	1.133	0.838	0.192	0.616	2.882

Table 3.4 *Pairwise comparison of thorax anterior/posterior tilt for all steps and start, peak, and start and peak combined. Based on estimated marginal means.* [a]*Adjustment for multiple comparisons.*
**Mean difference is significant at the 0.05 level*

Table 3.4 shows the results of the repeated measures general linear model analyses, conducted to adjust for multiple comparisons of thorax anterior/posterior tilt across multiple steps at multiple time points (*i.e.* start and peak). These results indicate that when examining the effect of "group" on thorax anterior/posterior tilt for the start and peak for all 14 steps, a significant difference between the non-professional and professional groups (*i.e.* $p > 0.05$) was not obtained for the start, the peak, or when combining the start and peak of steps.

3.3.3.1.2 <u>Thorax Side Tilt</u>

Figures 3.29 and 3.30 indicate that for thoracic side tilt, the only significant difference between non-professional and professional dancers was found for the peak of the *grand jeté elancé en avants*. In terms of the group mean values, all dancers exhibited minimal deviation of the thorax from vertical (0°) in the coronal plane, with relatively small standard deviations, for the *pliés*, *battements, rises*, *and sautés*. For these steps, dancers held their thorax within 1° or 2° of the vertical for the start and peak of the movements. Overall, there is no observable trend when comparing values for mean thoracic side tilt between groups at the start and peak of each step. For the few steps where discrepancies between groups are indicated there is no consistent direction of this deviation.

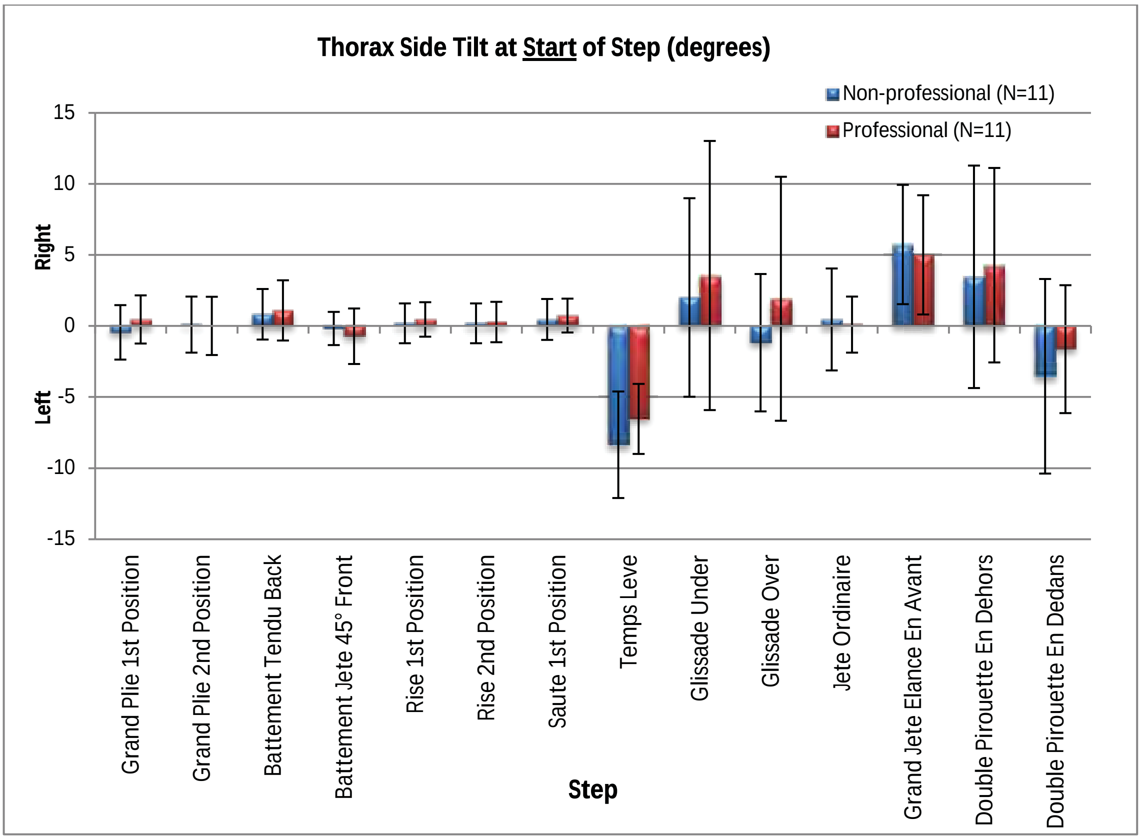


Figure 3.29 *Thorax side tilt at start of step.*
** Significant difference between groups (t-test: p<0.05). Error bars = ± 1 standard deviation*

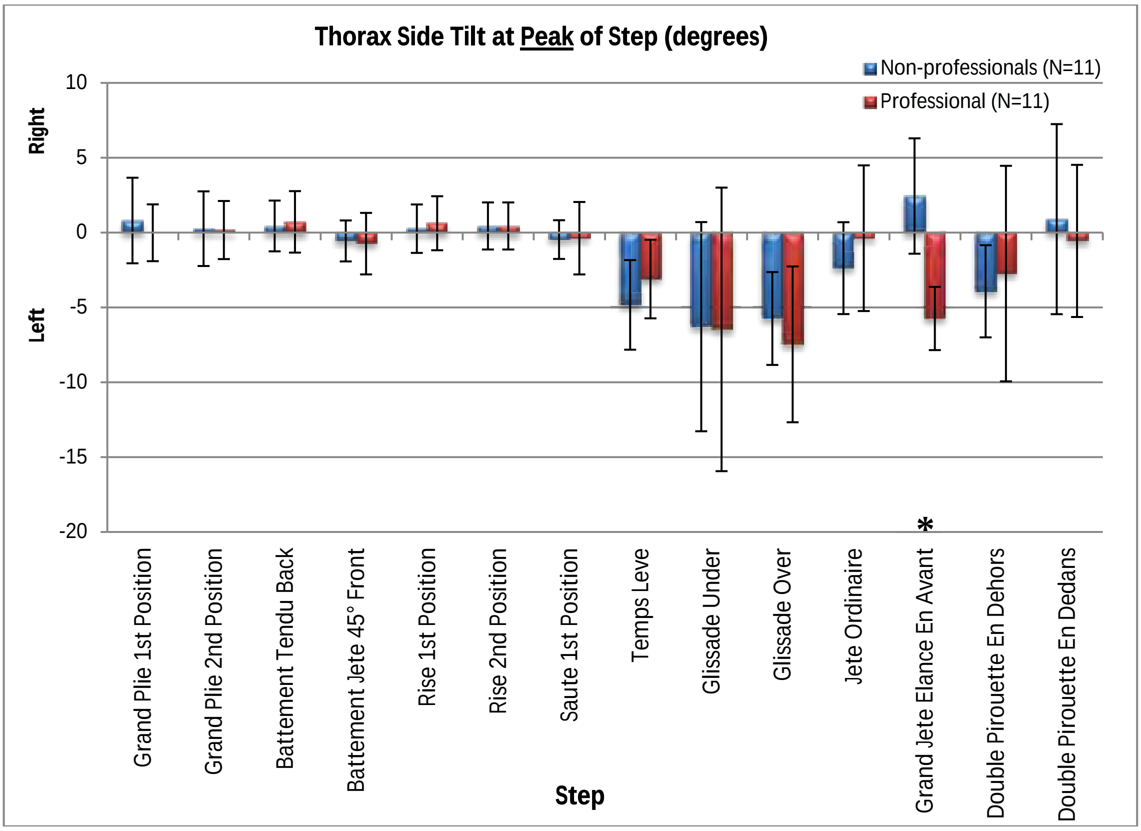


Figure 3.30 *Thorax side tilt at peak of step.*
** Significant difference between groups (t-test: p<0.05). Error bars = ± 1 standard deviation*

Time point	Mean Difference (°) (Non-professional - Professional)	Standard Error	p-value[a]	95% Confidence Interval for Difference[a]	
				Lower Bound	Upper Bound
Start	0.682	0.542	0.223	-0.449	1.812
Peak	-0.360	0.451	0.433	-1.293	0.573
Start & Peak	0.081	0.383	0.834	-0.717	0.880

***Table 3.5** Pairwise comparison of thorax side tilt for all steps and start, peak, and start and peak combined. Based on estimated marginal means. [a]Adjustment for multiple comparisons.*

Table 3.5 shows the results of the repeated measures general linear model analyses, conducted to adjust for multiple comparisons of thorax side tilt across multiple steps at multiple time points (*i.e.* start and peak). These results indicate that when examining the effect of "group" on thorax side tilt for all 14 steps, there is no significant difference (*i.e.* $p > 0.05$) for this variable between the non-professional and professional dancers for the start, the peak, or when combining the start and the peak of the steps.

3.3.3.2 Placement

The principle of 'placement' relates to the orientation and range of motion of the pelvis. Specifically, this principle is defined by the characteristics of maintaining a centred or neutral pelvic position and minimising pelvic displacement when executing movements of the lower limb. The kinematic measurement variables selected as biomechanical indicators of this principle are pelvic anterior/posterior tilt, pelvic obliquity, and pelvic - thoracic transverse rotation. Group means for these parameters at the start and peak of each step, and results for independent-samples t-tests between groups, are presented in Figures 3.31 – 3.36. Results of the repeated measures general linear model analysis, conducted to adjust for multiple comparisons, are presented in Tables 3.6 -3.8.

3.3.3.2.1 Pelvic Anterior/Posterior Tilt

Figures 3.31 and 3.32 indicate that for the majority of steps and time points, both groups of dancers held their pelvis in a position of anterior pelvic tilt. Significant differences between the non-professional and professional groups in mean pelvic anterior/posterior tilt were only obtained for the start of the *glissade under* and the peak of the *rise in first position*. Despite significant differences only being obtained for two parameters, a notable trend shown in figures 3.31 and 3.32 is one of increased anterior pelvic tilt for the non-professional group compared to the professional group for the majority of steps at both the start and peak time points.

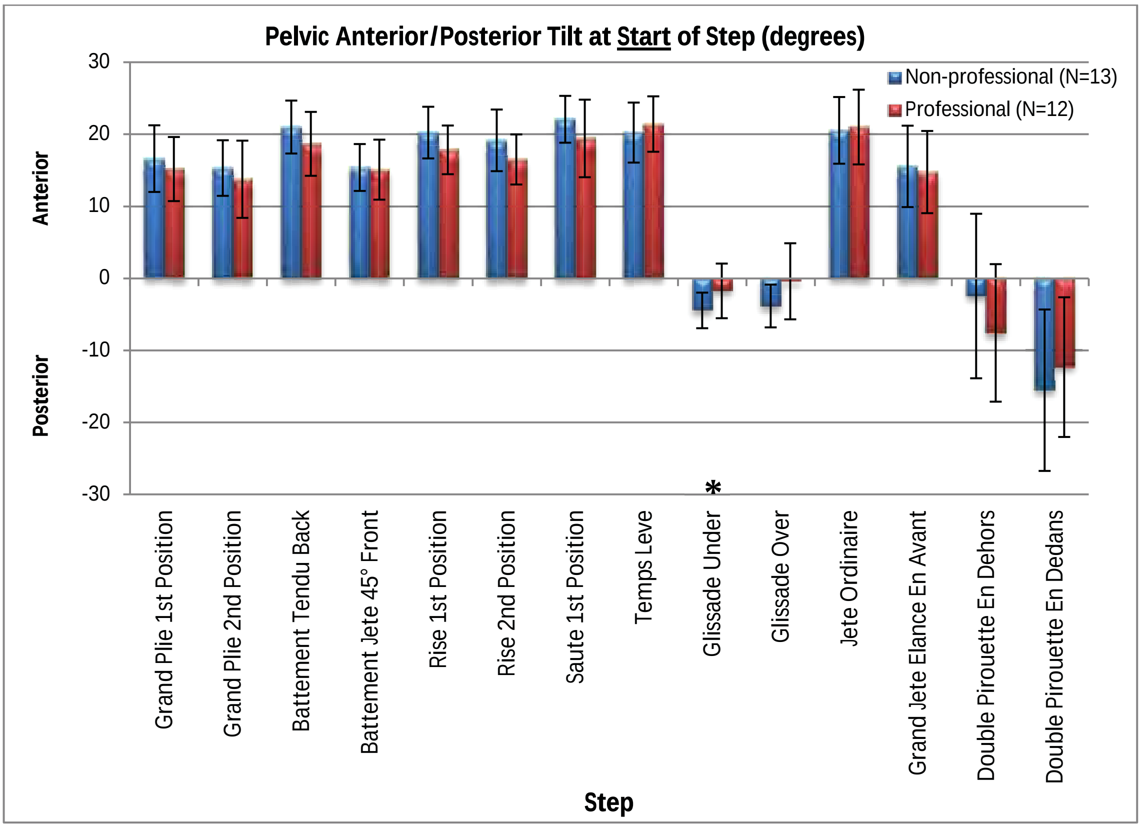


Figure 3.31 *Pelvic anterior/posterior tilt at start of step.*
** Significant difference between groups (t-test: p<0.05). Error bars = ± 1 standard deviation*

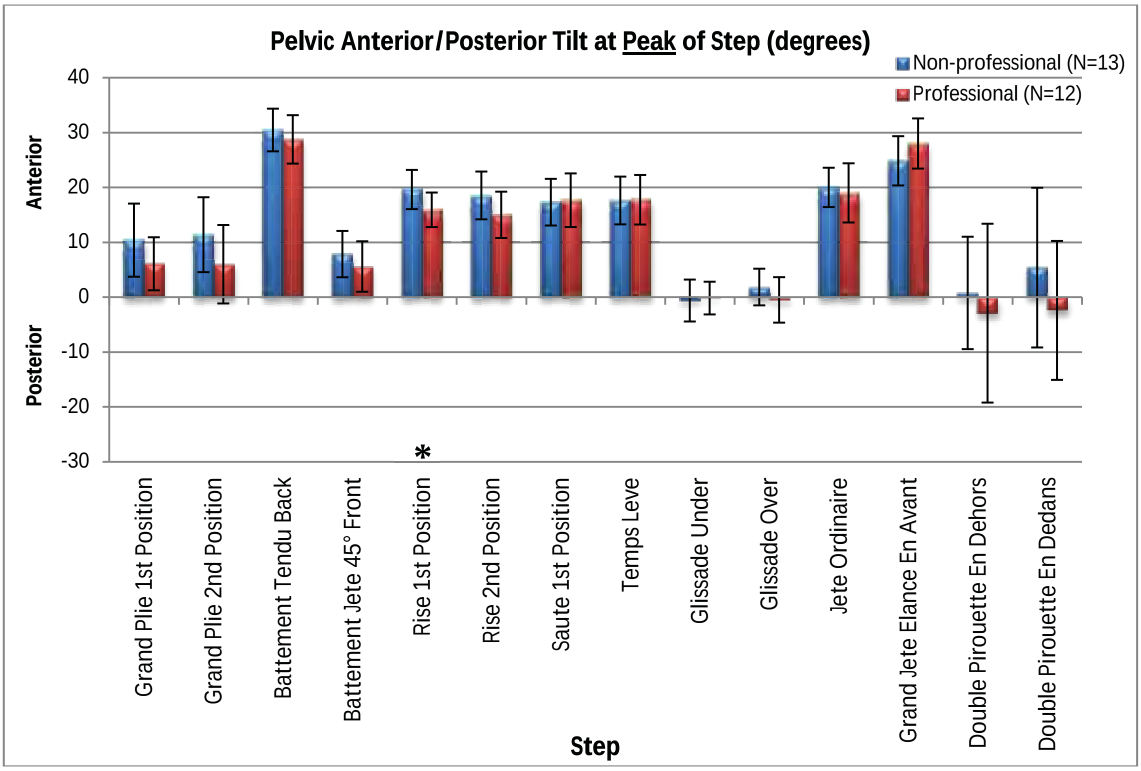


Figure 3.32 *Pelvic anterior/posterior tilt at peak of step.*
** Significant difference between groups (t-test: p<0.05). Error bars = ± 1 standard deviation*

Time point	Mean Difference (°) (Non-professional - Professional)	Standard Error	p-value[a]	95% Confidence Interval for Difference[a]	
				Lower Bound	Upper Bound
Start	-0.591	0.894	0.515	-2.440	1.259
Peak	-2.260*	0.926	0.023	-4.175	-0.344
Start & Peak	-1.425	0.775	0.079	-3.028	0.178

Table 3.6 *Pairwise comparison of pelvic anterior/posterior tilt for all steps and start, peak, and start and peak combined. Based on estimated marginal means.* [a]*Adjustment for multiple comparisons.*
**Mean difference is significant at the 0.05 level*

Table 3.6 shows the results of the repeated measures general linear model analyses, conducted to adjust for multiple comparisons of pelvic anterior/posterior tilt across multiple steps at multiple time points (*i.e.* start and peak). These results indicate that when examining the effect of "group" on pelvic anterior/posterior tilt for all 14 steps, there is no significant difference (*i.e.* $p > 0.05$) for this variable between the non-professional and professional dancers for the start, or when consider the start and the peak together, however there is a statistically significant difference when only considering the peak of the movements ($p = 0.023$).

3.3.3.2.2 Pelvic Obliquity

Figures 3.33 and 3.34 indicate that for both groups of dancers least pelvic obliquity was demonstrated at the start of the *pliés*, *battements*, *rises*, *and sautés*. Significant differences between the non-professional and professional groups in mean pelvic obliquity were only obtained for the start of the *jeté ordinaire*. For this step and time point, the non-professional group demonstrated increased lift of the pelvis on the supporting side of the body compared to the professional group. Overall, the mean values for pelvic obliquity are similar for each time point for each group for the majority of the 14 steps. However, despite not reaching statistical significance, there are a few steps and time points (start and peak *pirouette en dehors*, start and peak *pirouette en dedans*, peak *temps levé*, peak *gliassade under*, peak *glissade over*) where discrepancies between group means are evident, and for each of these the observable trend is that the professional group held their pelvis closer to neutral coronal plane 'placement' than the non-professional group.

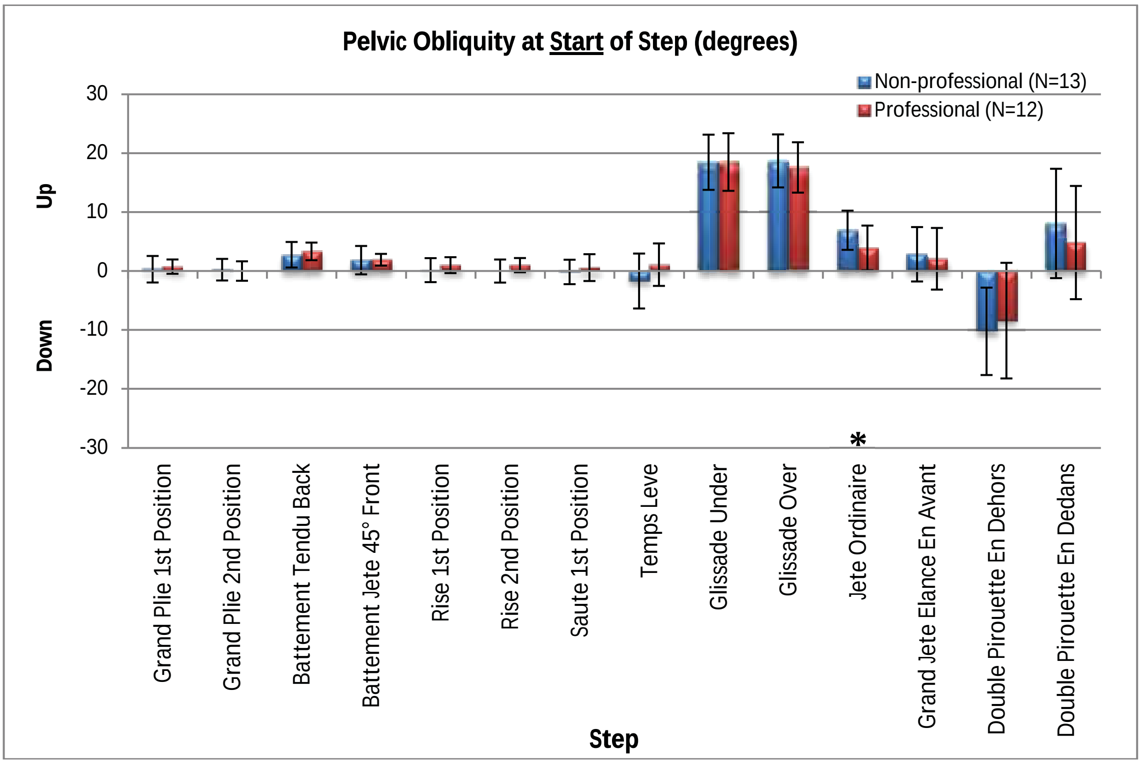


Figure 3.33 *Pelvic obliquity at start of step.*
** Significant difference between groups (t-test: p<0.05). Error bars = ± 1 standard deviation*

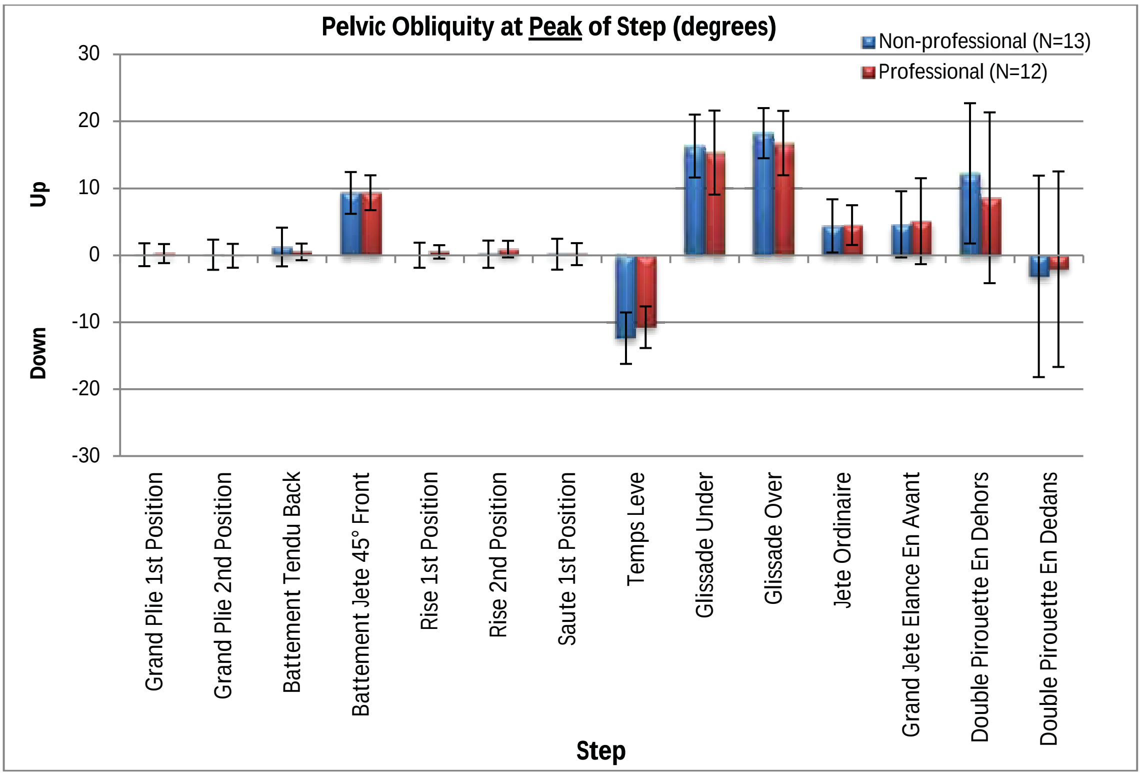


Figure 3.34*Pelvic obliquity at peak of step.*
** Significant difference between groups (t-test: p<0.05). Error bars = ± 1 standard deviation*

Time point	Mean Difference (°) (Non-professional - Professional)	Standard Error	p-value[a]	95% Confidence Interval for Difference[a]	
				Lower Bound	Upper Bound
Start	-0.005	0.660	0.995	-1.370	1.361
Peak	-0.159	0.846	0.852	-1.909	1.590
Start & Peak	-0.082	0.623	0.896	-1.370	1.206

Table 3.7 *Pairwise comparison of pelvic obliquity for all steps and start, peak, and start and peak combined. Based on estimated marginal means.* [a]*Adjustment for multiple comparisons.*

Table 3.7 shows the results of the repeated measures general linear model analyses, conducted to adjust for multiple comparisons of pelvic obliquity across multiple steps at multiple time points (*i.e.* start and peak). These results indicate that when examining the effect of “group” on pelvic obliquity for all 14 steps, there is no significant difference (*i.e.* p > 0.05) for this variable between the non-professional and professional dancers for the start, the peak, or when combining the start and the peak.

3.3.3.2.3 Pelvic – Thoracic Transverse Rotation

Figures 3.35 and 3.36 indicate that significant differences between the non-professional and professional groups in mean pelvic – thoracic transverse rotation were only obtained for the start and peak of the *grand jeté elancé en avant*, and the peak of the *battement jeté front*. There is no notable trend when comparing the direction of discrepancy in mean values for these statistically significant different steps and time points. For all other steps, the mean values for pelvic – thoracic transverse rotation are very similar for each time point for each group. For the few steps where discrepancies between groups are indicated there is no consistent direction of this deviation. Minimal pelvic – thoracic rotation was demonstrated for the start and peak of the *pliés, rises and sautés*.

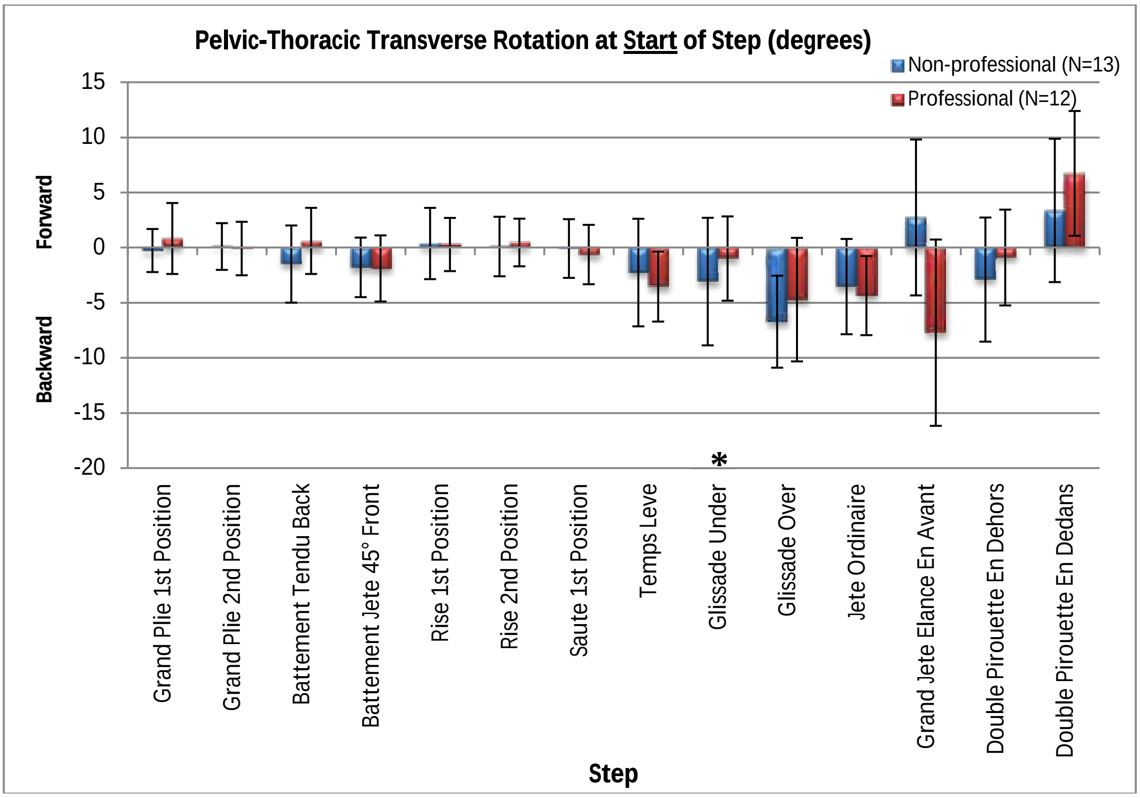


Figure 3.35 *Pelvic- thoracic transverse rotation at start of step.*
** Significant difference between groups (t-test: p<0.05). Error bars = ± 1 standard deviation*

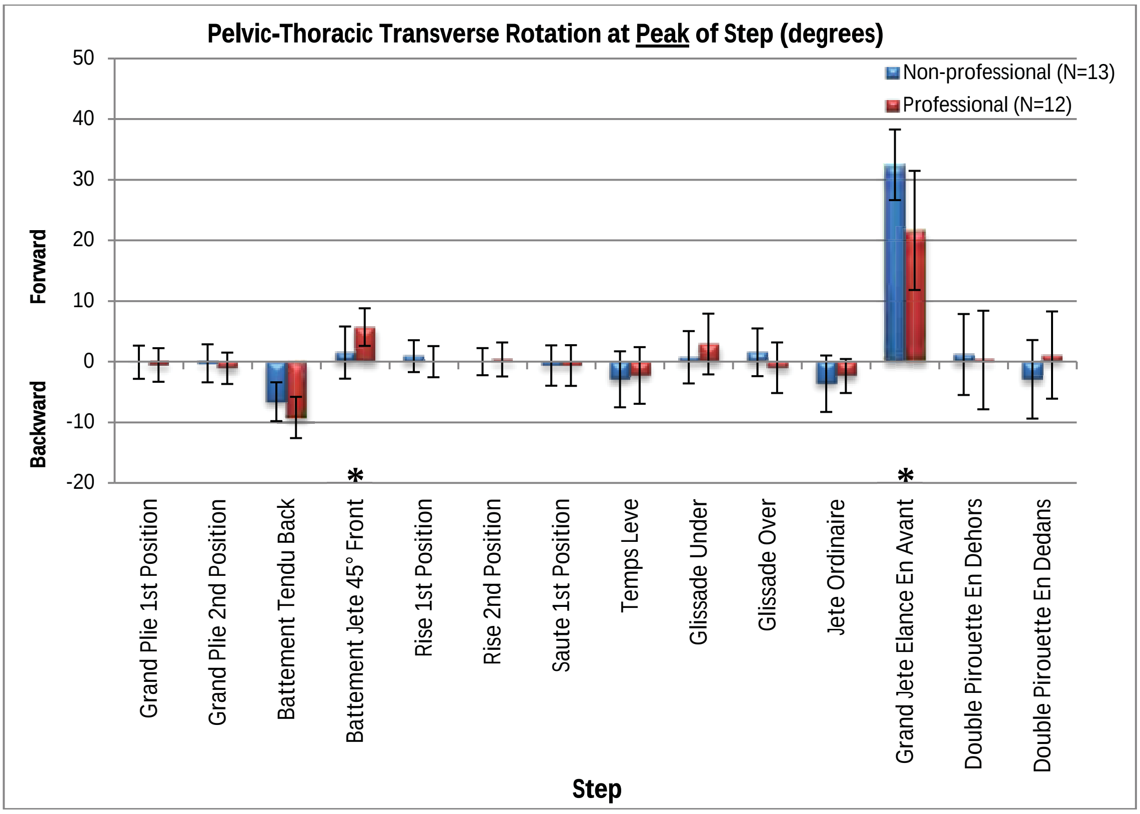


Figure 3.36 *Pelvic – thoracic transverse rotation at peak of step.*
** Significant difference between groups (t-test: p<0.05). Error bars = ± 1 standard deviation*

Time point	Mean Difference (°) (Non-professional - Professional)	Standard Error	p-value[a]	95% Confidence Interval for Difference[a]	
				Lower Bound	Upper Bound
Start	-0.032	0.828	0.969	-1.759	1.694
Peak	-0.281	0.714	0.698	-1.758	1.196
Start & Peak	-0.244	0.702	0.732	-1.707	1.220

Table 3.8 *Pairwise comparison of pelvic - thoracic transverse rotation obliquity for all steps and start, peak, and start and peak combined. Based on estimated marginal means. [a]Adjustment for multiple comparisons.*

Table 3.8 shows the results of the repeated measures general linear model analyses, conducted to adjust for multiple comparisons of pelvic - thoracic transverse rotation across multiple steps at multiple time points (*i.e.* start and peak). These results indicate that when examining the effect of "group" on pelvic - thoracic transverse rotation for all 14 steps, there is no significant difference (*i.e.* p > 0.05) for this variable between the non-professional and professional dancers for the start, the peak, or when combining the start and the peak.

3.3.3.3 *Turnout*

The principle of turnout relates to the rotation of the lower limb in the transverse plane. Specifically, this principle is defined by the characteristics of the dancer trying to achieve and maintain maximal external transverse plane rotation of the lower limb so as to increase the external foot progression angle. The kinematic measurement variables selected as biomechanical indicators of this principle are hip transverse plane rotation and ankle transverse plane rotation. Group means for these parameters at the start and peak of each step, and results for independent-samples t-tests between groups, are presented in Figures 3.37 – 3.40. Results of the repeated measures general linear model analysis, conducted to adjust for multiple comparisons, are presented in Tables 3.9 and 3.10.

3.3.3.3.1 *Hip Transverse Rotation*

Figures 3.37 and 3.38 depict that both groups of dancers exhibit external hip rotation for the start and peak of all steps except the *grand jeté elancé en avants*. There is a clear trend of increased external hip rotation demonstrated by the professional dancers compared to the non-professional dancers at the start and peak of the majority of steps. The only steps and time points for which this was not the case was the start of the *jeté ordinaire*, the peak of the *grand plié in second position*, and the peak of the *grand jeté elancé en avants*. Significant differences between groups in hip external rotation were obtained for 8 of the 14 steps at the start time point, and for 7 of the 14 steps at the peak time point.

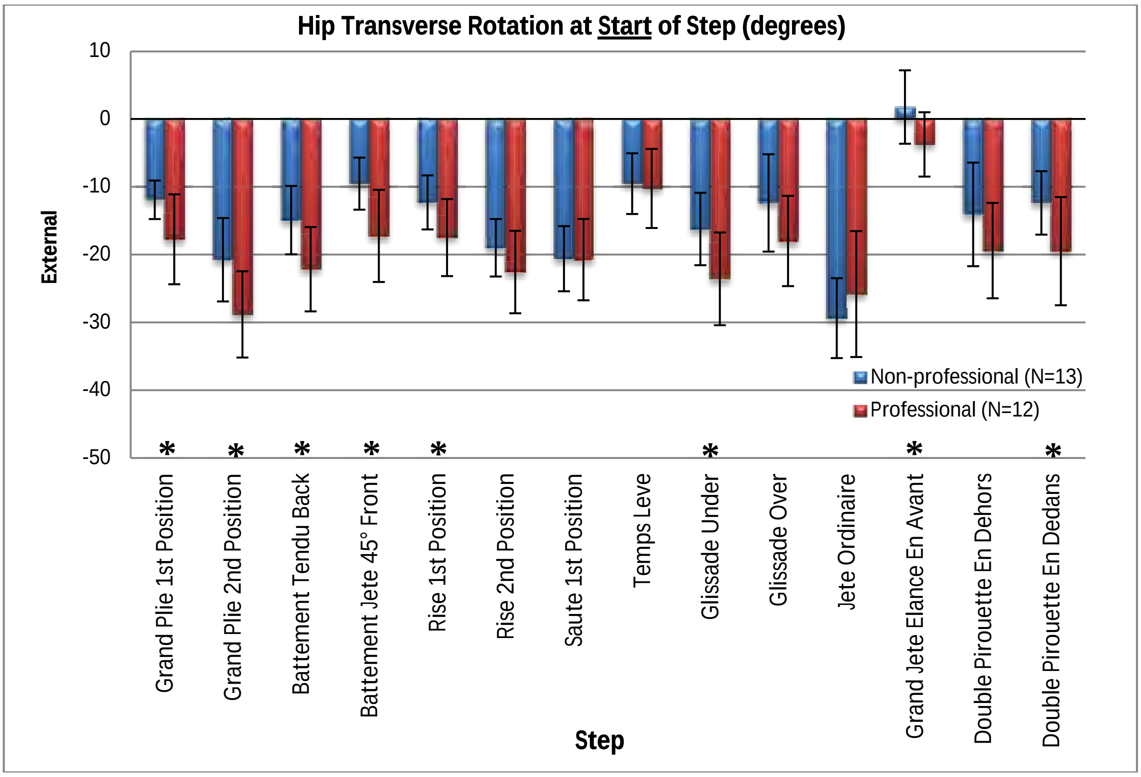


Figure 3.37 *Hip transverse rotation at start of step.*
** Significant difference between groups (t-test: p<0.05). Error bars = ± 1 standard deviation*

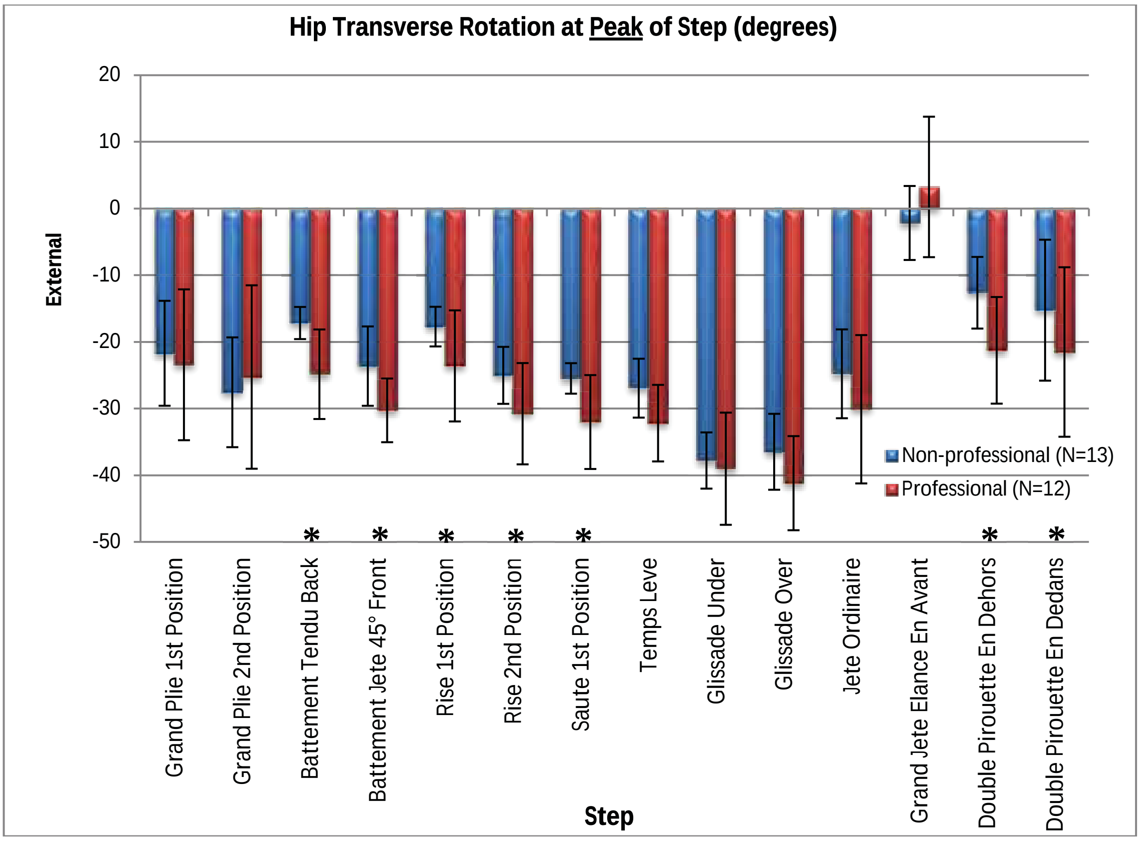


Figure 3.38 *Hip transverse rotation at peak of step.*
** Significant difference between groups (t-test: p<0.05). Error bars = ± 1 standard deviation*

Time point	Mean Difference (°) (Non-professional - Professional)	Standard Error	p-value[a]	95% Confidence Interval for Difference[a]	
				Lower Bound	Upper Bound
Start	-4.704*	1.209	0.001	-7.205	-2.204
Peak	-4.137*	1.799	0.031	-7.859	-0.416
Start & Peak	-4.421*	1.438	0.005	-7.395	-1.447

Table 3.9 *Pairwise comparison of hip transverse rotation for all steps and start, peak, and start and peak combined. Based on estimated marginal means.* [a]*Adjustment for multiple comparisons.*

Table 3.9 shows the results of the repeated measures general linear model analyses, conducted to adjust for multiple comparisons of hip transverse rotation across multiple steps at multiple time points (*i.e.* start and peak). These results indicate that when examining the effect of “group” on hip transverse rotation for all 14 steps, there is a significant difference (*i.e.* $p < 0.05$) for this variable between the non-professional and professional dancers. When considering all steps and time points, the professional dancers exhibited a mean value of 4.4° more external hip rotation than the non-professional dancers for the start, the peak, and when combining the start and the peak.

3.3.3.3.2 <u>Ankle Transverse Rotation</u>

Figures 3.39 and 3.40 depict a trend of increased external ankle rotation demonstrated by the professional dancers compared to the non-professional dancers at the start and peak of the majority of steps. The few steps and time points for which this was not the case were the start of the *grand plié in first position*, the peak of the *grand plié in second position*, the peak of the *sauté in first position*, the peak of the *jeté ordinaire*, and the start and peak of the *grand jeté elancé en avants*. Despite an observable trend of increased external ankle rotation demonstrated by the professional dancers compared to the non-professionals, significant differences between groups in ankle external rotation were only obtained for 3 of the 14 steps at the start time point, and for 2 of the 14 steps at the peak time point.

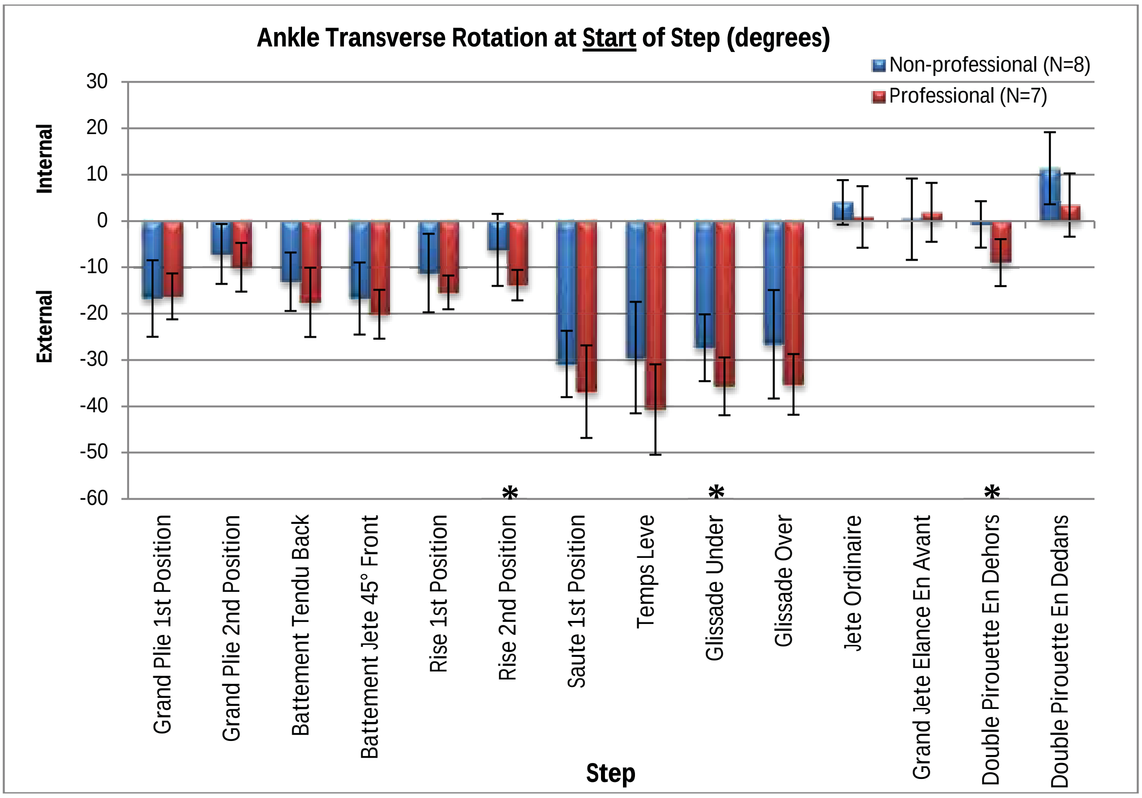


Figure 3.39 *Ankle transverse rotation at start of step.*
** Significant difference between groups (t-test: $p<0.05$). Error bars = ± 1 standard deviation*

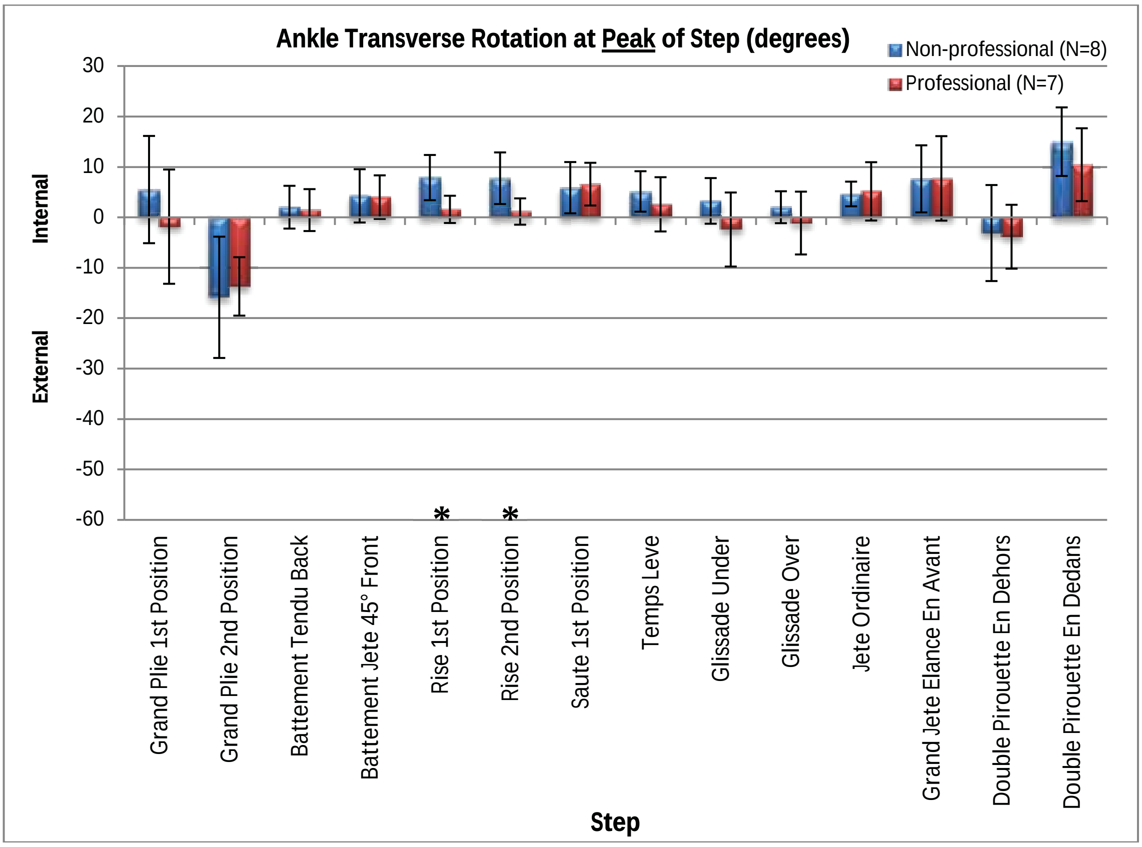


Figure 3.40 *Ankle transverse rotation at peak of step.*
** Significant difference between groups (t-test: $p<0.05$). Error bars = ± 1 standard deviation*

Time point	Mean Difference (°) (Non-professional - Professional)	Standard Error	p-value[a]	95% Confidence Interval for Difference[a]	
				Lower Bound	Upper Bound
Start	-5.292*	2.393	0.046	-10.461	-0.123
Peak	-1.640	1.650	0.331	-5.053	1.774
Start & Peak	-3.871	1.891	0.061	-7.957	0.215

Table 3.10 *Pairwise comparison of ankle transverse rotation for all steps and start, peak, and start and peak combined. Based on estimated marginal means.* [a]*Adjustment for multiple comparisons.*

Table 3.10 shows the results of the repeated measures general linear model analyses, conducted to adjust for multiple comparisons of ankle transverse rotation across multiple steps at multiple time points (*i.e.* start and peak). These results indicate that when examining the effect of "group" on ankle transverse rotation for all 14 steps, on average the professionals exhibited 5.3° more external ankle rotation than the non-professional dancers for the start, but for the peak, and when combining the start and the peak, there are not a significant differences (*i.e.* $p > 0.05$) for this variable between the non-professional and professional dancers.

3.3.3.4 Extension

The principle of extension relates to the extension of the lower limb in the sagittal plane. Specifically, this principle is defined by the characteristics of the dancer trying to achieve maximal extension at the knee and ankle joints in order to create an elongated and lengthened appearance of the limb in accordance with the aesthetic requirements of the classical ballet art form. The kinematic measurement variables selected as biomechanical indicators of this principle are knee flexion/extension and ankle dorsi/plantarflexion. Group means for these parameters at the start and peak of each step, and results for independent-samples t-tests between groups, are presented in Figures 3.41 – 3.44. Results of the repeated measures general linear model analysis, conducted to adjust for multiple comparisons, are presented in Tables 3.11 and 3.12.

3.3.3.4.1 Knee Flexion/Extension

Figures 3.41 and 3.42 show group means for knee flexion/extension at the start and peak of the steps for which maximum knee extension is required at these time points. Data are omitted for the start of the steps in the *jump*, *glissade* and *jeté* movement categories, and the peak of the steps in the *plié* movement category, because maximum knee extension is not required at these time points for these steps. Figures 3.41 and 3.42 show that for most steps, both groups of dancers achieve a position of knee hyperextension, but there is a clear trend of increased knee extension demonstrated by the professional dancers compared to the non-professional dancers at the start and peak of all 14 steps. Significant differences between groups in knee flexion/extension were obtained at the start time point for 5 of the 8 steps for which maximum knee extension was required at this time point. Significant differences were obtained at the peak time point for 5 of the 12 steps for which maximum knee extension was required at this time point.

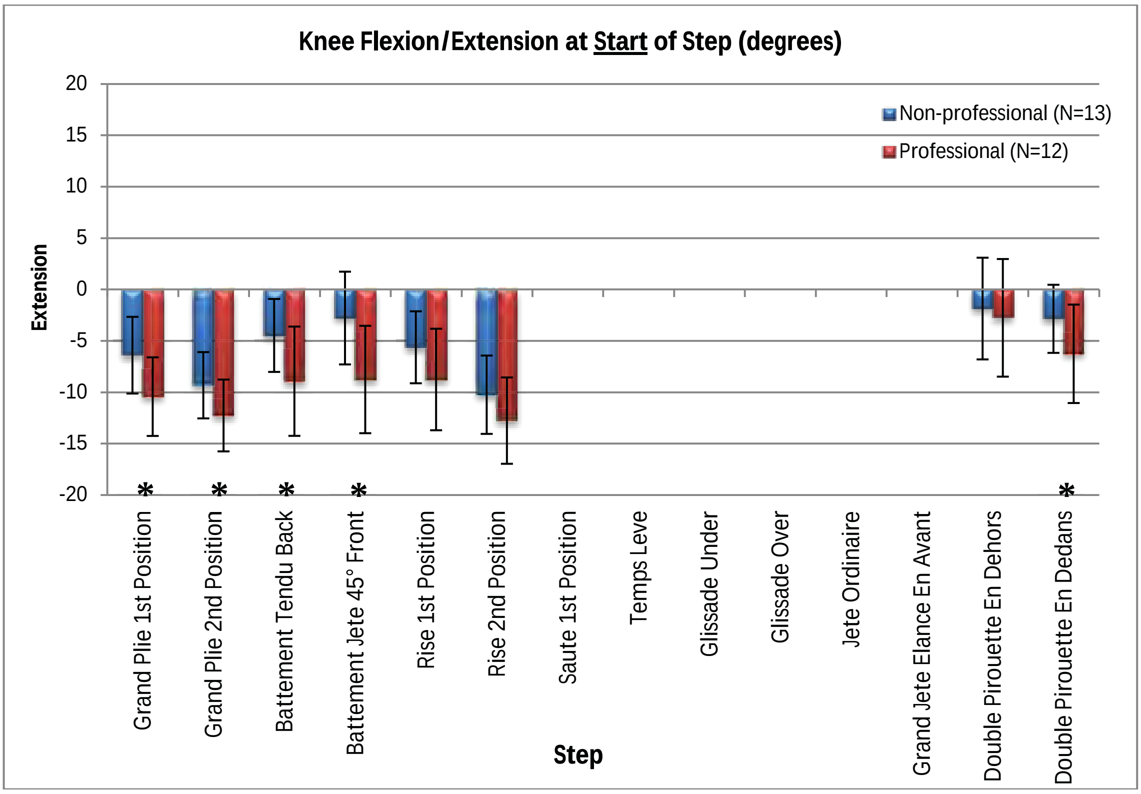


Figure 3.41 *Knee flexion/extension at start of step.*
** Significant difference between groups (t-test: p<0.05). Error bars = ± 1 standard deviation*

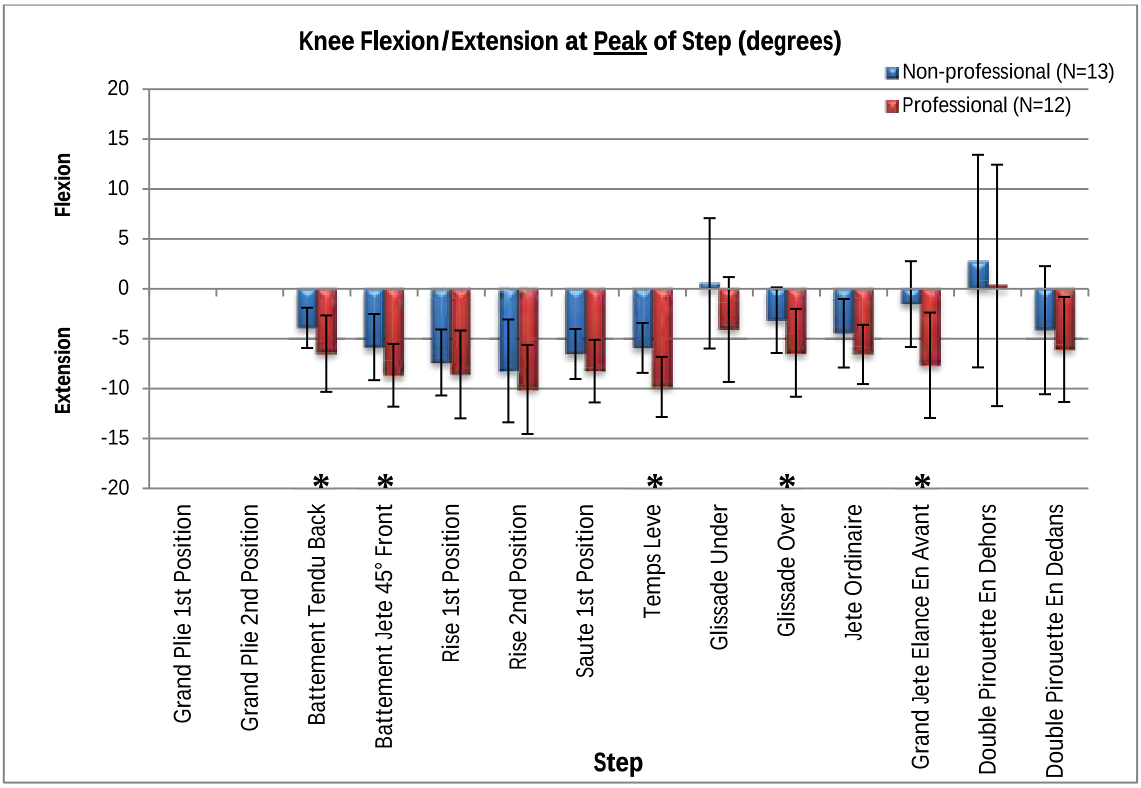


Figure 3.42 *Knee flexion/extension at peak of step.*
** Significant difference between groups (t-test: p<0.05). Error bars = ± 1 standard deviation*

Time point	Mean Difference (°) (Non-professional - Professional)	Standard Error	p-value[a]	95% Confidence Interval for Difference[a]	
				Lower Bound	Upper Bound
Start	-2.979*	1.227	0.023	-5.511	-0.447
Peak	-2.881*	1.281	0.034	-5.532	-0.230
Start & Peak	-3.097*	1.201	0.017	-5.582	-0.612

Table 3.11 *Pairwise comparison of knee flexion/extension for all steps and start, peak, and start and peak combined. Based on estimated marginal means.* [a]*Adjustment for multiple comparisons.*

Table 3.11 shows the results of the repeated measures general linear model analyses, conducted to adjust for multiple comparisons of knee flexion/extension across multiple steps at multiple time points (*i.e.* start and peak). These results indicate that when examining the effect of “group” on knee flexion/extension for all 14 steps, there is a significant difference (*i.e.* $p < 0.05$) for this variable between the non-professional and professional dancers. When considering all steps and time points, the professional dancers exhibited a mean value of 3.0° more knee extension than the non-professional dancers for the start, the peak, and when combining the start and peak timepoints.

3.3.3.4.2 Ankle Dorsi/Plantarflexion

Figures 3.43 and 3.44 show group means for ankle dorsi/plantarflexion at the start and peak of the steps for which maximum ankle plantarflexion is required at these time points. Data are omitted for the start of all steps except the *pirouette en dehors* and *pirouette en dedans*, and for the peak of the steps in the *plié* category of movement. This is because maximum ankle plantarflexion is not required at these time points for these steps. Figures 3.36 and 3.37 show that for the majority of steps and time points, both groups of dancers achieved a mean of at least 40° plantarflexion, and a trend of increased ankle plantarflexion demonstrated by the professionals compared to the non-professional is observed for the start of the *pirouette en dehors*, and for the peak of all steps. Significant differences between groups in ankle dorsi/plantarflexion were not obtained at the start of the *pirouettes en dehors* or *pirouette en dedans*. Significant differences were obtained at the peak time point for 4 of the 14 steps for which maximum ankle plantarflexion was required at this time point.

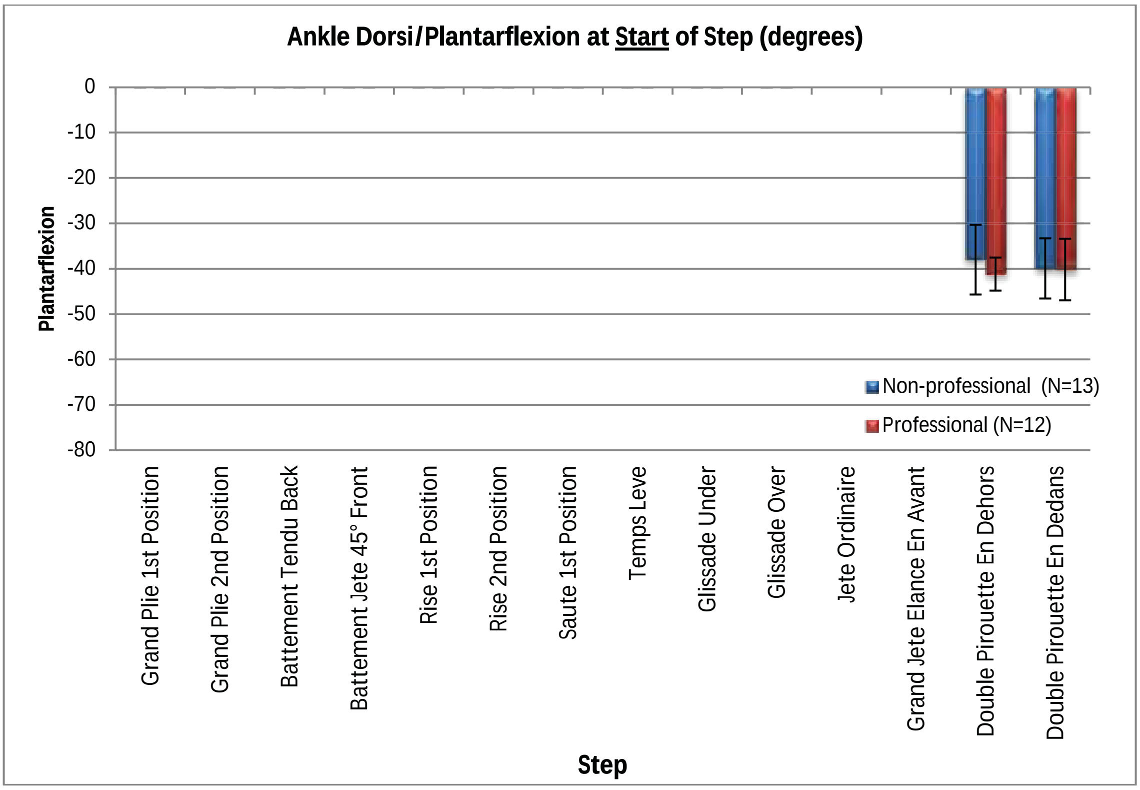


Figure 3.43 *Ankle dorsi/plantarflexion at start of step.*
** Significant difference between groups (t-test: $p<0.05$). Error bars = ± 1 standard deviation*

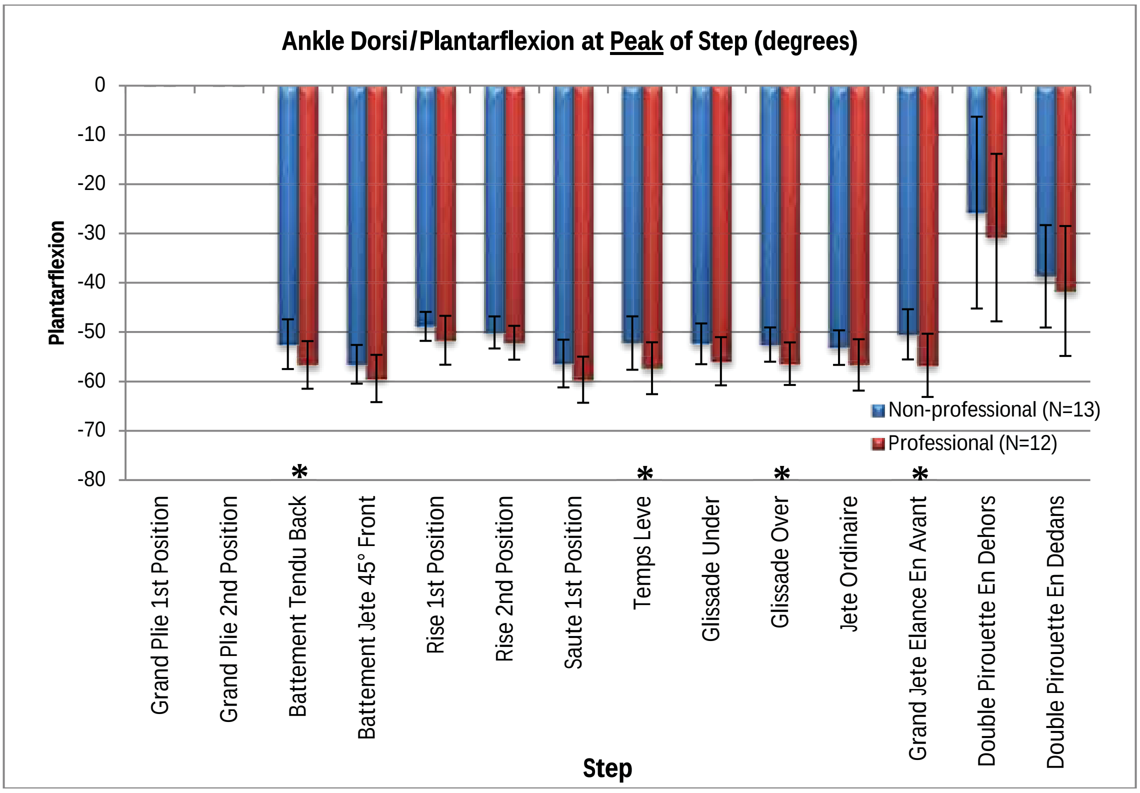


Figure 3.44 *Ankle dorsi/plantarflexion at peak of step.*
** Significant difference between groups (t-test: p<0.05). Error bars = ± 1 standard deviation*

Time point	Mean Difference (°) (Non-professional - Professional)	Standard Error	p-value[a]	95% Confidence Interval for Difference[a]	
				Lower Bound	Upper Bound
Start	-1.202	2.044	0.562	-5.421	3.016
Peak	-3.802*	1.621	0.028	-7.156	-0.449
Start & Peak	-3.503*	1.564	0.035	-6.737	-0.268

Table 3.12 *Pairwise comparison of ankle dorsi/plantarflexion for all steps and start, peak, and start and peak combined. Based on estimated marginal means.* [a]*Adjustment for multiple comparisons.*

Table 3.12 shows the results of the repeated measures general linear model analyses, conducted to adjust for multiple comparisons of ankle dorsi/plantarflexion across multiple steps at multiple time points (*i.e.* start and peak). These results indicate that when examining the effect of "group" on ankle dorsi/plantarflexion for all 14 steps, there is a significant difference (*i.e.* p > 0.05) for this variable between the non-professional and professional dancers. When considering all steps, compared to the non-professional dancers the professional dancers exhibited 3.8° more plantarflexion at the peak of the steps, and 3.5° more plantarflexion for the start and peak time points combined.

Summaries of the results for the repeated measures general linear model analyses for each of the nine kinematic measurement variables are presented in Tables 3.13 – 3.15. These tables show that using this form of statistical analysis, in which adjustments were made for multiple comparisons of the same variable across multiple steps, of all of the 9 measurement variables, statistically significant differences in group means were only obtained for 3 variables at the start of the steps, for 4 variables at the peak of the steps, and for 3 variables when considering both the start and peak together. Most notably, significant differences between groups were found for hip transverse rotation and knee extension when considering start and peak data seperately, and also when combining start and peak time points. These parameters fall into 2 of the 4 fundamental principle categories that were indentied for classical ballet technique, *i.e.* 'turnout' and 'extension'.

Biomechanical Principle	Kinematic Variable	Mean Difference (Non-professional - Professional)	Std. Error	p-value [a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
Alignment	Thorax Ant/Post Tilt	-0.468	0.808	0.569	-2.153	1.218
	Thorax Side Tilt	0.682	0.542	0.223	-0.449	1.812
Placement	Pelvic Ant/Post Tilt	-0.591	0.894	0.515	-2.440	1.259
	Pelvic Obliquity	-0.005	0.660	0.995	-1.370	1.361
	Pelvic - Thoracic Rotation	-0.032	0.828	0.969	-1.759	1.694
Turnout	Hip Rotation	-4.704*	1.209	0.001	-7.205	-2.204
	Ankle Rotation	-5.292*	2.393	0.046	-10.461	-0.123
Extension	Knee Extension	-2.979*	1.227	0.023	-5.511	-0.447
	Ankle Plantarflexion	-1.202	2.044	0.562	-5.421	3.016

Table 3.13 *Summary of pairwise comparisons between groups at start of step, using repeated measures general linear model. Based on estimated marginal means.*
** The mean difference is significant at the 0.05 level.*
[a] Adjustment for multiple comparisons.

Biomechanical Principle	Kinematic Variable	Mean Difference (Non-professional - Professional)	Std. Error	p-value [a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
Alignment	Thorax Ant/Post Tilt	-1.313	0.937	0.175	-3.252	0.627
	Thorax Side Tilt	-0.360	0.451	0.433	-1.293	0.573
Placement	Pelvic Ant/Post Tilt	-2.260*	0.926	0.023	-4.175	-0.344
	Pelvic Obliquity	-0.159	0.846	0.852	-1.909	1.590
	Pelvic - Thoracic Rotation	-0.281	0.714	0.698	-1.758	1.196
Turnout	Hip Rotation	-4.137*	1.799	0.031	-7.859	-0.416
	Ankle Rotation	-1.640	1.650	0.331	-5.053	1.774
Extension	Knee Extension	-2.881*	1.281	0.034	-5.532	-0.230
	Ankle Plantarflexion	-3.802*	1.621	0.028	-7.156	-0.449

***Table 3.14** Summary of pairwise comparisons between groups at peak of step, using repeated measures general linear model. Based on estimated marginal means.*
** The mean difference is significant at the 0.05 level.*
[a] Adjustment for multiple comparisons.

Biomechanical Principle	Kinematic Variable	Mean Difference (Non-professional - Professional)	Std. Error	p-value [a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
Alignment	Thorax Ant/Post Tilt	1.133	0.838	0.192	0.616	2.882
	Thorax Side Tilt	0.081	0.383	0.834	-0.717	0.880
Placement	Pelvic Ant/Post Tilt	-1.425	0.775	0.079	-3.028	0.178
	Pelvic Obliquity	-0.082	0.623	0.896	-1.370	1.206
	Pelvic - Thoracic Rotation	-0.244	0.702	0.732	-1.707	1.220
Turnout	Hip Rotation	-4.421*	1.438	0.005	-7.395	-1.447
	Ankle Rotation	-3.871	1.891	0.061	-7.957	0.215
Extension	Knee Extension	-3.097*	1.201	0.017	-5.582	-0.612
	Ankle Plantarflexion	-3.503*	1.564	0.035	-6.737	-0.268

***Table 3.15** Summary of pairwise comparisons between groups for start and peak time points combined, using repeated measures general linear model. Based on estimated marginal means.*
** The mean difference is significant at the 0.05 level.*
[a] Adjustment for multiple comparisons.

3.3.4 Analysis of Fundamental Principles with Respect to Movement Categories and Steps

To further analyse the kinematic data with respect to the four fundamental principles of classical ballet technique, results are also displayed in a test matrix in which each movement category and step is displayed against each fundamental biomechanical principle. The test matrix, presented in Table 3.16, summarises the result of the independent-samples t-tests between the professional and non-professional groups for each kinematic variable.

Table 3.16 shows that with respect to the 'Seven Movements of Dance' (Noverre, 1760), the *pliés* were most effective in detecting deviations in 'alignment', specifically in thoracic anterior/posterior tilt. Significant differences between groups were obtained for the start and peak of the *grand plié in first position*, and for the start of the *grand plié in second position.*

The *battement* steps were able to detect differences between groups in two of the fundamental principles, 'turnout' and 'extension'. Statistically significant differences were obtained for all inter-group comparisons of hip rotation (*i.e.* 'turnout') and knee extension (*i.e.* 'extension') for the start and peak of the *battement tendu derriere* and the *battement jeté devant.* Deviations in 'turnout' were also highlighted well by the *relevé* and *pirouette* movement categories. For the *relevés in first and second position*, differences between groups were observed for hip rotation and ankle rotation, while for the *pirouettes*, differences in hip rotation were detected. None of the movement categories were effective in detecting differences in 'placement'. That is, significant differences between groups were not obtained for pelvic variables for more than one step per movement category. Thus, with respect to the four fundamental principles of classical ballet technique, the movement categories of 'bend' (*plié*), 'stretch' (*battement*), 'rise' (*relevé*), and 'turn' (*tour*) were best able to detect kinematic differences between groups across the multiple time points.

MOVEMENT CATEGORY	STEP	PHASE	BIOMECHANICAL PRINCIPLE								
			ALIGNMENT		PLACEMENT			TURNOUT		EXTENSION	
			Thorax Ant/ Post Tilt	Thorax Side Tilt	Pelvic Ant/ Post Tilt	Pelvic Obliq	Pelvic-Thorax Rot	Hip Ext Rot	Ankle Ext Rot	Knee Ext	Ankle Plant-flex
1. BEND (*PLIÉ*)	*Grand Plié 1st Position*	Start	✓	✗	✗	✗	✗	✓	✗	✓	n/a
		Peak	✓	✗	✗	✗	✗	✗	✗	n/a	n/a
	Grand Plié 2nd Position	Start	✓	✗	✗	✗	✗	✓	✗	✓	n/a
		Peak	✗	✗	✗	✗	✗	✗	✗	n/a	n/a
2. STRETCH (*BATTEMENT*)	*Battement Tendu Back*	Start	✗	✗	✗	✗	✗	✓	✗	✓	n/a
		Peak	✗	✗	✗	✗	✗	✓	✗	✓	✓
	Battement Jeté 45° Front	Start	✗	✗	✗	✗	✗	✓	✗	✓	n/a
		Peak	✗	✗	✗	✗	✓	✓	✗	✓	✗
3. RISE (*RELEVÉ*)	*Rise 1st Position*	Start	✗	✗	✗	✗	✗	✓	✗	✗	n/a
		Peak	✗	✗	✓	✗	✗	✓	✓	✗	✗
	Rise 2nd Position	Start	✗	✗	✗	✗	✗	✗	✓	✗	n/a
		Peak	✗	✗	✗	✗	✗	✓	✓	✗	✗
4. JUMP (*SAUTÉ*)	*Sauté 1st Position*	Start	✗	✗	✗	✗	✗	✗	✗	n/a	n/a
		Peak	✗	✗	✗	✗	✗	✓	✗	✗	✗
	Temps Levé	Start	✗	✗	✗	✗	✗	✗	✗	n/a	n/a
		Peak	✓	✗	✗	✗	✗	✗	✗	✓	✓
5. GLIDE (*GLISSÉ*)	*Glissade Under*	Start	✗	✗	✓	✗	✓	✓	✓	n/a	n/a
		Peak	✗	✗	✗	✗	✗	✗	✗	✗	✗
	Glissade Over	Start	✗	✗	✗	✗	✗	✗	✗	n/a	n/a
		Peak	✗	✗	✗	✗	✗	✗	✗	✓	✓
6. DART (*ELANCÉ*)	*Jeté Ordinaire*	Start	✗	✗	✗	✓	✗	✗	✗	n/a	n/a
		Peak	✗	✗	✗	✗	✗	✗	✗	✗	✗
	Grand Jeté Elancé En Avants	Start	✗	✗	✗	✗	✓	✓	✗	n/a	n/a
		Peak	✗	✓	✗	✗	✓	✗	✗	✓	✓
7. TURN (*TOUR*)	*Double Pirouette En Dehors*	Start	✗	✗	✗	✗	✗	✗	✓	✗	✗
		End	✗	✗	✗	✗	✗	✓	✗	✗	✗
	Double Pirouette En Dedans	Start	✗	✗	✗	✗	✗	✓	✗	✓	✗
		End	✗	✗	✗	✗	✗	✓	✗	✗	✗

***Table 3.16** Kinematic Variable Test Matrix*

✓ = Significant difference between professional and non-professional groups (t-test: $p<0.05$)

✗ = No significant difference between professional and non-professional groups (t-test: $p \geq 0.05$)

n/a = Not applicable (Joint movement not executed at time point, (e.g. maximum knee extension and plantarflexion not required at peak of grand pliés in first and second positions).

Movement categories for which a significant difference between professional and non-professional groups occurs for at least 3 of the 4 time points analysed. Steps for which statistically significant differences in group means occurred for at least 3 of the 4 four fundamental principles

The test matrix in Table 3.16 also enables comparison of the extent to which statistically significant differences in group means occur for each measurement variable in each individual step. Results show that there are only 3 steps out of 16 for which statistically significant differences in start and peak group means occur for at least 3 of the 4 four fundamental principles of classical ballet technique. These three steps are the *grand plié in first position*, the *battement tendu back*, and the *grand jeté elancé en avants.*

Based on the data depicted in Table 3.16, further results for the three steps for which statistically significant differences in group means were obtained for at least 3 of the 4 four fundamental principles are presented in Figures 3.45 to 3.55. These figures display the time-normalised group means from the start (0%) to finish (100%) of each step for the measurement variables for which statistically significant differences in group means were obtained. For each figure, the vertical line represents the instant at which the peak of the movement occurs. A red vertical line at the start and/or peak of the movement indicates that a statistically significant difference in group means was obtained at that time point.

Significant differences in group means at the start and/or peak of the *grand plié in first position* occurred for thorax anterior/posterior tilt, hip transverse rotation and knee flexion/extension, these kinematic variables fall into the Alignment, Turnout and Extension principle categories, respectively. Figures 3.45 and 3.46 show that for the *grand plié in first position*, the professional group demonstrated increased thorax extension and increased external hip rotation not only at the start and peak of this step, but at all time points throughout the step. Figure 3.47 indicates that although a statistically significant difference in knee flexion/extension was obtained at the start of the *grand plié in first position*, the degree of knee flexion throughout the rest of the movement was very similar between groups.

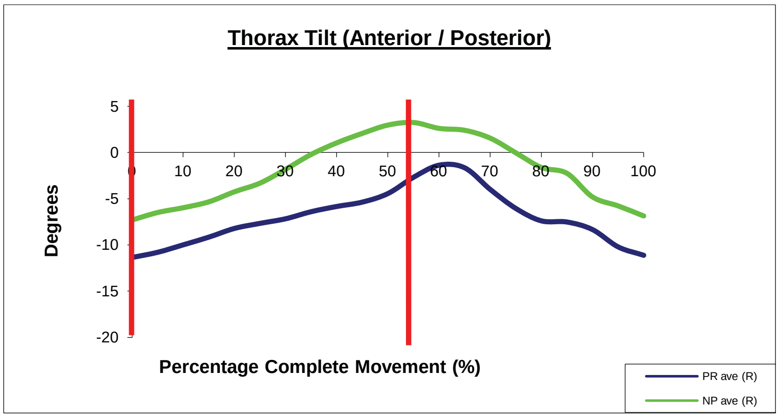


Figure 3.45 *Thorax anterior/posterior tilt for grand plié in first position. Blue line = mean for professional dancers; green line = mean for non-professional dancers. Vertical lines indicate step start and peak (Red line = significant difference at time point; Black line = no significant difference at time point)*

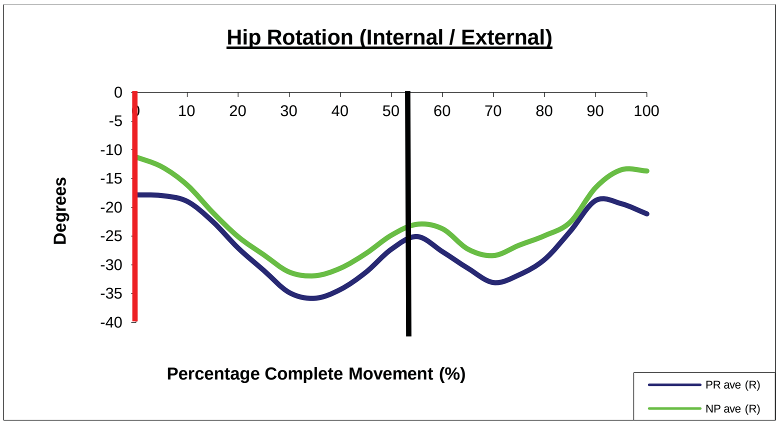


Figure 3.46 *Hip transverse rotation for grand plié in first position. Blue line = mean for professional dancers; green line = mean for non-professional dancers. Vertical lines indicate step start and peak (Red line = significant difference at time point; Black line = no significant difference at time point)*

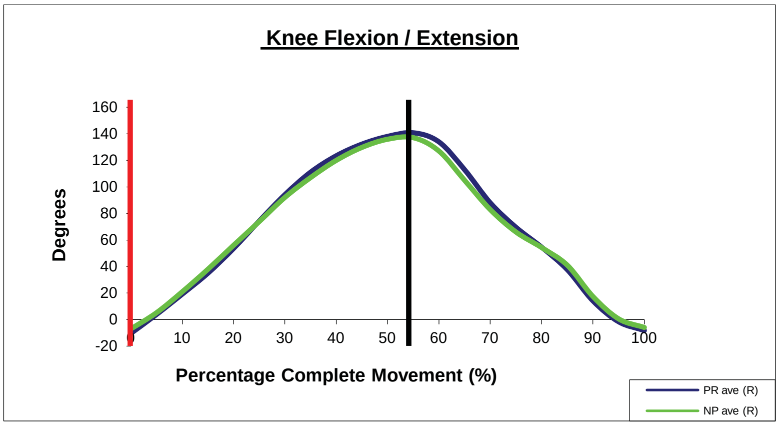


Figure 3.47 *Knee flexion/extension for grand plié in first position. Blue line = mean for professional dancers; green line = mean for non-professional dancers. Vertical lines indicate step start and peak (Red line = significant difference at time point; Black line = no significant difference at time point)*

Significant differences in group means at the start and/or peak of the *battement jeté front* occurred for pelvic-thoracic transverse rotation, hip transverse rotation, and knee flexion/extension, these kinematic variables fall into the Placement, Turnout and Extension principle categories, respectively. Figure 3.48 indicates that although the professional group started and finished the *battement jeté front* with their pelvis-thoracic rotation in a similar position to the non-professionals (*i.e.* close to neutral), between 20% and 80% of the movement the professional group demonstrated increased forward pelvic rotation with respect to the thorax compared to the amateur group. For the other variables for which statistically significant differences were obtained at the start and/or peak of the *battement jeté front*, the direction of difference between group means at the start and/or peak time points was consistent throughout the movement. That is, the professional group demonstrated increased external hip rotation (Figure 3.49) and increased knee extension (Figure 3.50) throughout the entire movement compared to the non-professional group.

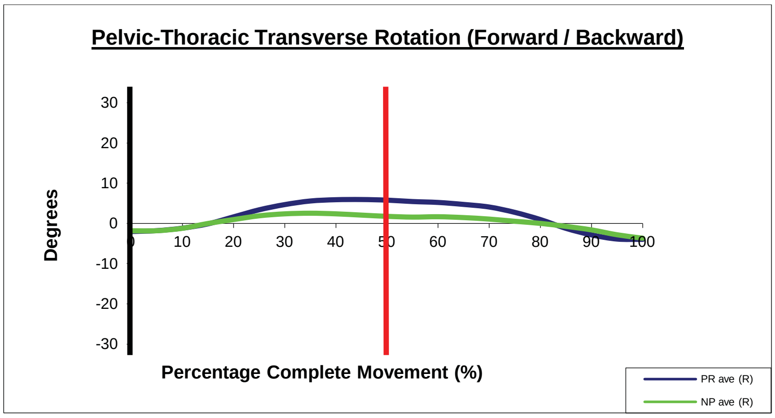


Figure 3.48: *Pelvic-thoracic transverse rotation for battement jeté front. Blue line = mean for professional dancers; green line = mean for non-professional dancers. Vertical lines indicate step start and peak (Red line = significant difference at time point; Black line = no significant difference at time point)*

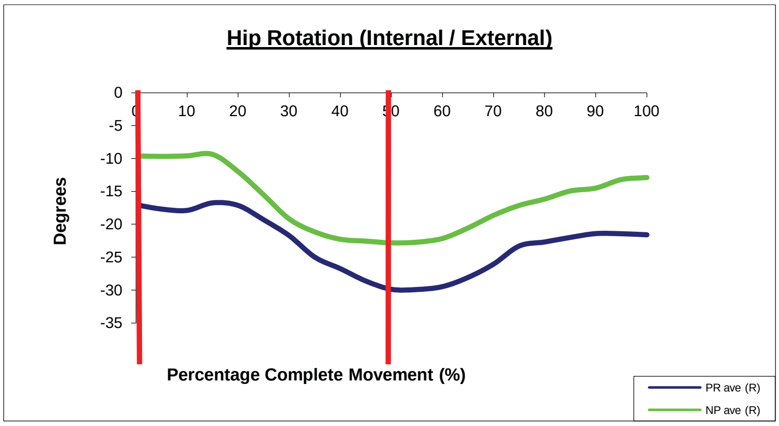


Figure 3.49: *Hip transverse rotation for battement jeté front. Blue line = mean for professional dancers; green line = mean for non-professional dancers. Vertical lines indicate step start and peak (Red line = significant difference at time point; Black line = no significant difference at time point)*

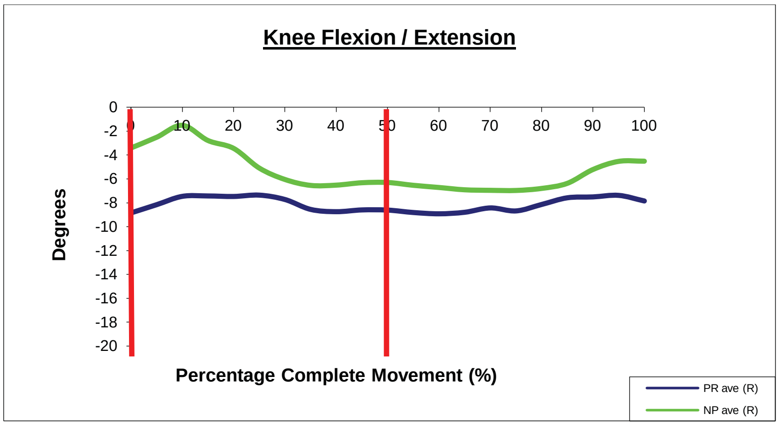


Figure 3.50 *Knee flexion/extension for battement jeté front. Blue line = mean for professional dancers; green line = mean for non-professional dancers. Vertical lines indicate step start and peak (Red line = significant difference at time point; Black line = no significant difference at time point)*

Significant differences in group means at start and/or peak of the *grand jeté elancé en avants* occurred for thorax side tilt, pelvic-thoracic transverse rotation, hip transverse rotation, knee flexion/extension and ankle dorsi/plantarflexion. These kinematic variables fall into each of the four principle categories of Alignment, Placement, Turnout and Extension, respectively. Figure 3.52 shows that the professional group exhibited decreased forward rotation of the pelvis relative to the thorax compared to the amateurs for the entire *grand jeté elancé en avants*. For all other variables for which statistically significant differences were obtained at the start and/or peak of the *grand jeté elancé en avants*, there is variability in the direction of difference between group means for other time points within the movement cycle. For example, as shown in Figures 3.54 and 3.55, the professionals show increased knee extension and ankle plantarflexion from the start to approximately 70% of the step (*i.e.* the airborne phase), but increased knee flexion and ankle dorsiflexion from about 75% -100% (*i.e.* the landing phase) of the movement. The direction of difference between group means for thorax side tilt and hip transverse rotation also fluctuates during the movement cycle, as indicated in Figures 3.51 and 3.53 respectively.

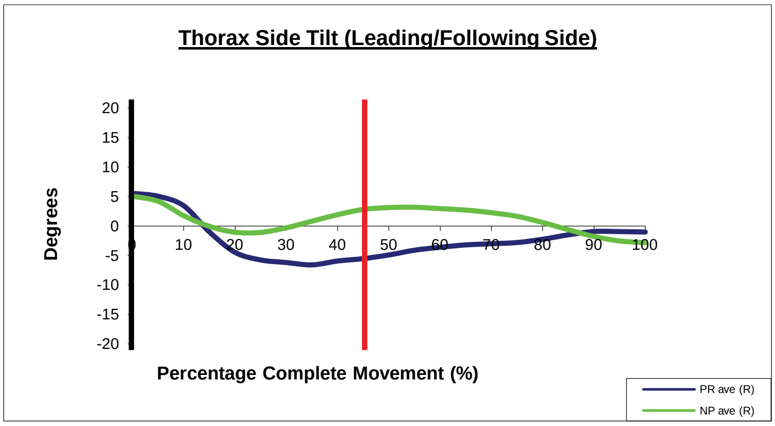


Figure 3.51 *Thorax side tilt for grand jeté elancé en avants. Blue line = mean for professional dancers; green line = mean for non-professional dancers. Vertical lines indicate step start and peak (Red line = significant difference at time point; Black line = no significant difference at time point)*

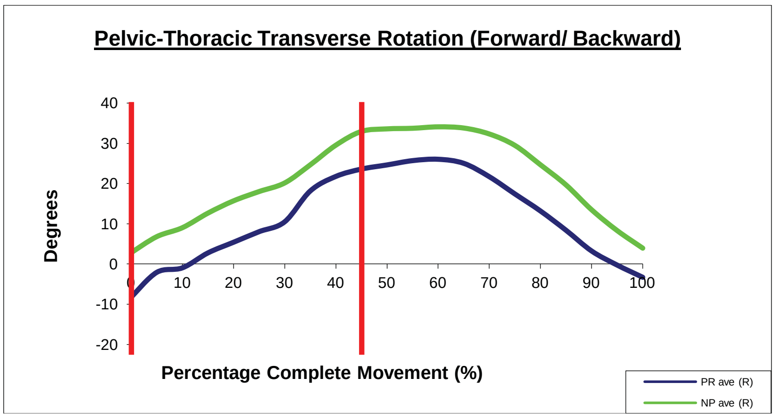


Figure 3.52 *Pelvic-thoracic transverse rotation for grand jeté elancé en avants. Blue line = mean for professional dancers; green line = mean for non-professional dancers. Vertical lines indicate step start and peak (Red line = significant difference at time point; Black line = no significant difference at time point)*

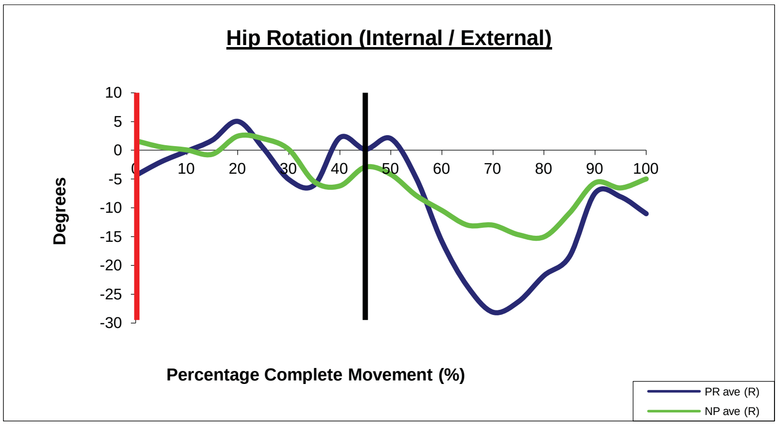


Figure 3.53 *Hip transverse rotation for grand jeté elancé en avants. Blue line = mean for professional dancers; green line = mean for non-professional dancers. Vertical lines indicate step start and peak (Red line = significant difference at time point; Black line = no significant difference at time point)*

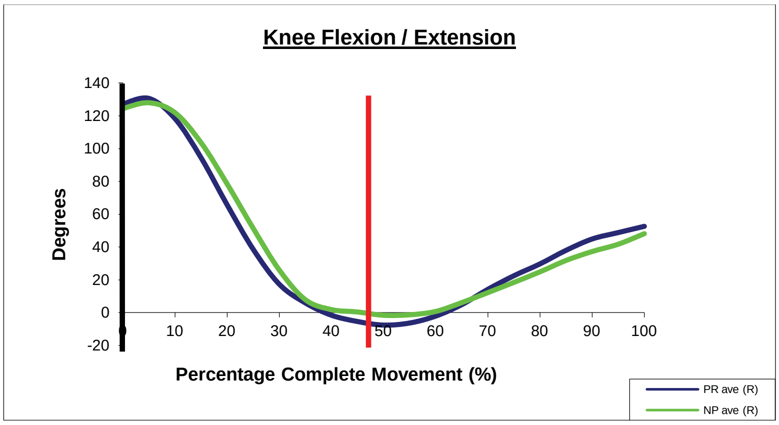


Figure 3.54 *Knee flexion/extension for grand jeté elancé en avants. Blue line = mean for professional dancers; green line = mean for non-professional dancers. Vertical lines indicate step start and peak (Red line = significant difference at time point; Black line = no significant difference at time point)*

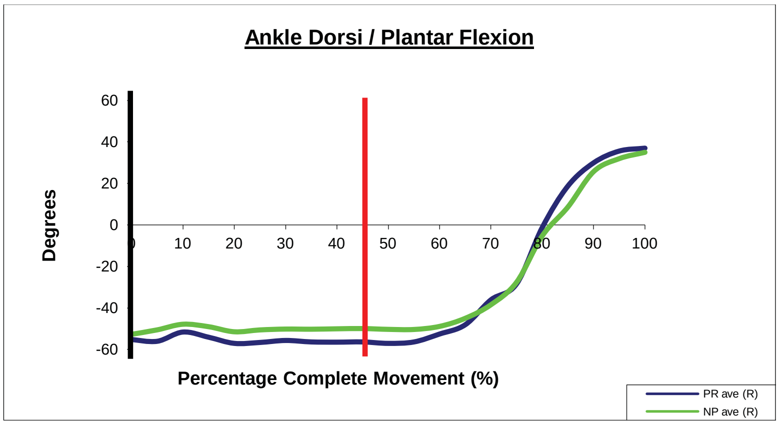


Figure 3.55 *Ankle dorsi/plantarflexion for grand jeté elancé en avants. Blue line = mean for professional dancers; green line = mean for non-professional dancers. Vertical lines indicate step start and peak (Red line = significant difference at time point; Black line = no significant difference at time point).*

3.4 Discussion

A primary aim of this project was to determine the degree to which professional and non-professional ballet dancers execute classical ballet technique relative to the theoretical principles, thereby identifying the level of agreement between the theoretical concepts and practical execution of the technique at an elite level. To achieve this, 3D joint and segment angular displacement data were obtained for professional and non-professional ballet dancers performing 14 different ballet steps. The steps could each be assigned to one of seven different movement categories identified in Noverre's 'Seven Movements of Dance' (Noverre, 1760). Kinematic data were obtained for the thorax, pelvis, hips, knees and ankles, and comparisons of mean kinematic variables were made between the professional and non-professional dancers. Data were analysed with respect to the four fundamental principles of classical ballet technique, as defined and described in Section 2.1.2. The four fundamental principles are 'alignment', 'placement', 'turnout', and 'extension', and results will be discussed in relation to each of these principles

3.4.1 Alignment

In the literature review, the principle of 'alignment' was defined as "maintaining verticality of the torso". To measure this biomechanical principle, the kinematic variables of thoracic anterior/posterior tilt and thoracic side tilt were selected as the relevant parameters. In accordance with the theoretical principles of classical ballet, it could be expected that professional dancers would hold their thorax in a more vertically neutral position within the sagittal and coronal planes than non-professionals, and that this would be revealed by smaller deviations of the thorax from vertical (*i.e.* from a measurement value of zero) at the start and peak of each step. When considering all steps collectively, there were no significant differences between groups in thoracic anterior/posterior tilt or thoracic side tilt at either the start or peak of the movements. This finding is in agreement with that of Wilson *et al.* (2004), who found no significant inter-group difference in sagittal and coronal plane trunk motion between novice and skilled dancers, when using 3D motion analysis to investigate the *grand rond de jambe en l'air*.

Interestingly, although in the dance literature much emphasis has been placed on maintaining a verticality of the torso, it is evident from the current data (Figures 3.27 & Figure 3.28) that both non-professional and professional dancers hold their torso in a position of posterior thoracic tilt, rather than a truly vertical position. In support of this finding, Wilson *et al.* (2004) reported mean anterior/posterior trunk angles of 18° posterior for skilled ballet dancers performing the *grand rond de jambe en l'air*. When comparing the data obtained for thoracic anterior/posterior tilt during execution of classical ballet steps with that for normal adult gait, it is evident that the thoracic position adopted by ballet dancers is extreme in relation to normal human locomotion. Sartor *et al.* (1999) and Chung *et al.* (2010) reported mean global sagittal plane thoracic positions of approximately 0° (*i.e.* approximately vertical), throughout the normal adult human gait cycle. Thus, it seems than on a practical level, the desired aesthetic of 'grand manners' and extreme elegance and poise is actually achieved by taking one's thorax beyond a position of verticality, into a position of posterior thoracic tilt. This was demonstrated to a moderate extent by non-professional dancers, and in some instances to an even greater degree by highly skilled professional dancers.

With respect to the range of thoracic motion exhibited throughout the ballet steps, it is evident that for stationary steps that do not require knee flexion or elevation off the floor (*i.e. battements; rises*) there was little range of thorax anterior/posterior motion between the step start and peak for either group of dancers. That is, at the start and peak of the *battements*, and *rises*, all mean values for thoracic anterior/posterior tilt for both groups of dancers were held within the range of 5 - 9° posterior thoracic tilt. Thus, despite some discrepancy with the dance literature in relation to the thorax position being posterior rather than vertical, thoracic range of motion data are consistent with the literature in the sense that while executing these steps the dancers held their thorax very still, as indicted by Blasis (1820, p24) "while dancing, the body must remain quiet and absolutely steady", and more recently by the Royal Academy of Dance (1997, p8), "the position of the back and sides is retained as far as possible". For the steps that required deep (*i.e. grand pliés)* or moderate (*i.e. sautés; temps levés; jetés*) knee flexion the range of thoracic anterior/posterior motion throughout the steps was not so limited. For example, at the point of maximum knee flexion during the *grand pliés*, both groups of dancers moved their thorax approximately 12° anterior of their starting position, and during the countermovement knee bend required for push-off into the airborne *sautés, temps levés* and *jetés,* all dancers moved their thorax to a more anterior position than that displayed during most other steps. Also of note, is the observation that it was at the peak of the steps requiring vertical elevation off the floor (*i.e. sautés; temps levés)* for which the professional dancers demonstrated the greatest posterior tilt of the thorax. Therefore, this group exhibited a higher range of trunk anterior/posterior motion between the start and peak of the jumps (10° posterior) compared to the non-professionals (5° posterior). Such a result contradicts the theoretical principle that ballet dancers are supposed to keep their back still while performing jumps ("the dancer is required to jump with lightness and control, and to mask the effort by keeping the body erect", Royal Academy of Dance 1997, p79), in that practical data from highly skilled professionals indicate that some movement of the trunk is in fact functionally necessary.

From a purely biomechanical perspective, increased forward lean of the trunk during a *grand plié*, and during the preparatory phase of jumps, facilitates greater torque and hence greater power generation for the hip extension required for ascent out of the *grand plié* and for push-off into the air for jumps (Lees *et al.*, 2004; Vanrenterghem *et al.,* 2008). Vanrenterghem *et al.* (2008) studied the effect of forward inclination on the power output in vertical jumping. Subjects (non-dancers) performed maximal countermovement jumps as they naturally would (*i.e.* with some forward thoracic flexion during preparation), and also while holding the trunk as upright as possible. The more upright position of the thorax during the countermovement preparation phase resulted in a 27% reduction in hip joint flexion, and a consequent statistically significant decrease of 37% in hip extension torque and power during push-off. The maximum jump height reached was also significantly decreased by 10%. So, in the context of classical ballet jumps, the theoretically desired aesthetic of minimal anterior/posterior motion of the trunk, yet maximum elevation off the floor, are biomechanically opposing goals. The increased range of trunk motion demonstrated by the professionals compared to the non-professionals indicates therefore that the more highly skilled group may be sacrificing some of the theoretically ideal aesthetics required of the trunk, in order to access maximal hip extension power during push-off, thus potentially enabling an aesthetically impressive increase in jump height.

In relation to thoracic side tilt, for the symmetrical steps where the right and left sides of the body performed the same movement (*i.e. pliés*, *rises*, *sautés*), all dancers exhibited very little thoracic movement in the coronal plane, and held their thorax within 1° or 2° of the vertical for the start and peak of the movements. This result is therefore in strong agreement with the definitions of the principle of 'alignment'. It was the steps which commenced while primarily balanced on a single leg (*i.e. temps levé, glissades*, *jetés*, *pirouettes*), that deviations from neutral in thoracic coronal movement were noted in both groups of dancers. For example, when executing the *temps levé* (*i.e.* single leg hop), all dancers displayed thoracic side tilt towards the supporting leg, and for the *glissades* (gliding step), thoracic side tilt was towards the direction of travel. Thus, as was the case for sagittal plane thoracic motion, larger ranges of motion in coronal plane thoracic movement are associated with the functional requirements of the step.

3.4.2 Placement

The principle of 'placement' has been described in the literature review as being "minimal displacement of the pelvis from a centred position" (Section 2.1.3.2). To assess this principle, pelvic positions with respect to the sagittal, coronal and transverse planes were measured. Analysis of the kinematic data relating to pelvic anterior/posterior tilt reveals that at the start and peak of the majority of steps, both groups of dancers held their pelvis in a position of at least 10° anterior tilt. At the start of the steps that commenced from a basic ballet stance, that is with straight knees, externally rotated hips, and upright posture (*i.e. pliés*, *battements*, *rises*), mean values for pelvic position ranged from 15° to 23° anterior for the non-professional dancers, and from 14° to 28° anterior for the professional dancers. Thus, it is evident that if one considers a biomechanically neutral or centred position to be 0°, *i.e.* the convention typically applied in quantitative biomechanical analysis, then the pelvis is very rarely actually held in a truly "neutral" position while executing classical ballet movements. This finding is supported by the studies of Gamboain *et al.* (1999; 2000), Deckert *et al.* (2007) and Holt *et al.* (2011) who all used 2D video analysis to measure pelvic tilt. For all of these studies the steps analysed were basic ballet movements in which neither leg was elevated off the floor. Pelvic tilt ranges for each of these studies were 7 - 23° anterior (Gamboian *et al.*, 1999; Gamboian *et al.*, 2000), 2 - 14° anterior (Holt *et al.*, 2011), and 9 - 19° anterior (Deckert *et al.*, 2007). The sagittal plane position of the pelvis typically adopted in normal human locomotion is approximately 10° anterior, with minimal excursion from this position occurring throughout the gait cycle (Perry, 1992; Schwartz, 2004). The results of the current study, as well as those of previous researchers, therefore indicate that on a practical level, the highly desired "neutral" position of the pelvis, referred to in the dance literature, is actually a position of anterior pelvic tilt, similar to that typically adopted during normal gait. Interestingly, even highly skilled professional ballet dancers do not achieve "correct" technique and 'placement' of the pelvis by altering their sagittal pelvic position from that typically held during normal locomotion.

Also of note in relation to the pelvic anterior/posterior tilt, is the observation that for steps in which one leg was moved to the front (*i.e. battement jeté devant* to 45°) or back (*i.e. battement tendu derriere*) of the body, the pelvis did in fact deviate from its starting position. This was observed for both groups of dancers. When moving the leg to the front in the *battement jeté devant,* the pelvis moved from a starting position of 15° anterior for both groups of dancers, to 8° and 5° anterior for professional and non-professional dancers, respectively. Such a result contradicts the dance literature, in that Grieg (1994, p41) for example, states that "in *battement* to the front, the pelvis should remain uninvolved", and White (1996, p83) writes "do not allow the buttocks to push or tuck under". For the step involving posterior leg movement, pelvic tilt increased to at least 25° anterior for both groups of dancers by the peak of the movements. Results showing involvement of the pelvis during movement of the leg to the front or back of the body in classical ballet (*grand rond de jambe en l'air* and *grand battements)* have also been reported by Wilson *et al.* (2004; 2007) and Bronner and Ojofeitimi (2011). Thus, despite considerable theoretical information indicating that ideally there should be limited movement of the pelvis in the sagittal plane when moving one leg to either the front or back of the body, research data show that the pelvis is involved, even when the foot of the 'working' leg remains in contact with the floor, as was the case for the battement *tendu derriere*. It should also be pointed out however, that when considering data from all steps combined, there was a significant difference in pelvic anterior/posterior tilt between the non-professional and professional dancers at the peak of the steps, with the professional dancers demonstrating a mean value of 2.2° less anterior tilt than the non-professionals. Given that there was not a significant difference between groups in this variable at the start of the movements, this finding suggests that although some pelvic movement did occur from start to peak, the more highly skilled ballet dancers were in fact able to perform the ballet steps with a decreased range of sagittal plane pelvic motion, compared to non-professional dancers.

With respect to pelvic obliquity, there was only one step and time point (*i.e.* start of *jeté ordinaire*) for which a significant difference was found between the professional and non-professional dancers. In this instance, the professional dancers exhibited raised pelvic obliquity of 4° on the supporting side, compared to 7° demonstrated by the non-professionals. This difference is consistent with many of the theoretical references to correct 'placement', (*e.g.* "the horizontal and/or parallel lines of pelvis and shoulder in relation to the parallel floor line, must not be upset" Lee, 1983, p209), in that it indicates that professional dancers are able to maintain their pelvis more closely to the horizontal, even when performing single-leg support movements such as the start of the *jeté ordinaire*. Despite this result, when all steps were considered collectively, there were no significant differences between groups in pelvic obliquity at the start, the peak, or for the start and peak combined. As was the case for thoracic side tilt, in relation to pelvic obliquity it was the symmetrical steps, where the right and left sides of the body performed the same movement (*i.e. pliés*, *rises*, *sautés*), that all dancers exhibited very little pelvic movement in the coronal plane. For these steps, all dancers held their pelvis within 1° of the horizontal for the start and peak of the movements, a result that also supports the definitions of the principle of 'placement'. However, pelvic obliquity for both groups deviated up to as much as 18° for asymmetrical steps that required sideways travel (*e.g. glissade under*), indicating that if a step involves movement from a single spot, then functionally it is necessary to involve pelvic coronal plane motion.

Also related to the principle of 'placement', is the observation that for the *battement jeté* to 45° front, both groups of dancers raised the pelvis on the working side (*i.e.* the side of leg movement) to 9° above the horizontal at the movement peak. A recurring theme in dance literature is that the pelvis should not be lifted when elevating the leg to the front (Vaganova, 1953; Karsavina, 1962; Grieg, 1994). Given that the dancers were only asked to elevate their leg to an angle of 45°, and that at best the literature relating to ballet technique only concedes that there is displacement of the pelvis when the working leg moves above 90° (Paskeva, 2002), this degree of pelvic movement for a relatively low leg elevation from highly skilled professional dancers is somewhat surprising. Such a result suggests that more coronal plane pelvis movement is demonstrated on a practical level than would be expected based on theoretical information alone.

Lastly in relation to 'placement', the kinematic variable of pelvic – thoracic transverse rotation will be discussed. For this variable, when considering all steps collectively, no significant differences between groups were obtained at the start, peak, or start and peak combined. The only individual steps or time points for which significant differences were found were the start of the *glissade under*, the peak of the *battement jeté* front to 45° and *grand jeté elancé en avants*. The result for the *battement jeté* is particularly interesting as it indicates that, in contradiction to the dance literature, when one leg is elevated in front of the body the pelvis and thorax do not necessarily remain facing the same plane. Many dance authors (Karsavina, 1962; Lawson, 1983; White, 1996; Schorer, 1999) have indicated that when one leg is elevated off the ground, the pelvis and thorax should remain parallel to each other and facing the same plane. However, the results obtained in the current study reveal that this was in fact the case for the non-professional dancers but not for the professional dancers. Although lifting the leg to a statistically similar height (Table 3.3), the professionals performed this movement with a pelvic - thoracic transverse rotation value of 6° at the peak of the movement, compared to only 1° for the non-professionals. Additionally, in the batt*ement tendu* to the back, although a significant difference was not obtained between groups for pelvic-thoracic transverse rotation, the data indicate that for the professional dancers up to 9° of rotation took place between the pelvis and thorax. This result is also in conflict with the theoretical suggestion that the pelvis and thorax should remain parallel or "square" to each other. Thus, the dance theory has again been challenged in practise as shown by the practical results obtained from highly skilled professional ballet dancers.

3.4.3 Turnout

The results relating to the principle of 'turnout' clearly indicate that professional dancers perform classical ballet steps with more external rotation of the hips than non-professional dancers. Whether considering the start, the peak, or the start and peak combined, significant differences between groups were found for this variable, with the professional dancers exhibiting an average of 4.4° more external hip rotation than the non-professionals. In terms of the theoretical dance literature, which clearly states that extreme external rotation of the hip joints is an essential characteristic of classical ballet technique, the current data are in strong agreement with this theoretical information, and add convincing evidence to support this theoretical concept.

It can be seen that at the start of the steps, the professionals' hip external rotation data ranged from 4° through to 29° external, while values at the peaks ranged from 3° internal to 41° external. On a practical level, there was therefore a considerable range in the degree of hip 'turnout' actively used by professional dancers. In discussing these values of hip external rotation data however, it is important to consider the possible effects of the Cardan angle rotation sequence on the values calculated. Lees *et al.* (2010) reported that pelvic data and sagittal hip, knee and ankle data are robust with regard to Cardan angle rotation sequence, but that hip transverse plane data are influenced by rotation sequence. In particular, hip internal/external rotation values varied across a range of 60° when six different rotation sequences were used, however this was only the case when hip flexion moved beyond 50° (Lees *et al.*, 2010). Below 50° hip flexion, hip internal/external rotation data were not affected by the rotation sequence. Based on this finding, since the majority of steps analysed in the current study did not involve hip flexion beyond 50°, it can be concluded that for most steps and time points the hip external rotation data can be considered to be a reasonable representation of the actual movement occurring at the joint. The step and time points for which hip transverse plane data may be inaccurate are the start and peak of the *grand jeté elancé en avants* (*i.e.* split leap). In this step, the working leg is thrust forward into hip flexion to facilitate the "split" position. Accordingly, the hip rotation data calculated for the start and peak of this step are considerably different to those for all other steps, with values reaching into the internal rotation range (Figure 3.38).

If the data for the *grand jeté elancé en avants* are not considered, then hip rotation data range from 10° to 40° external for the professional dancers across the start and peak of all steps. It has been stated (Hardaker *et al.*, 1984; Paskeva, 2002) that ideally dancers should strive to dance with as close as possible to 90° of external rotation on each lower limb, thus giving an overall appearance of 180° between the external progression line of each foot. Some dance texts state that close to all of this rotation should occur in the hip

(Paskeva, 2002) while others have said that only 60° - 70° of the external rotation actually occurs in the hip joint, with the rest of the rotation being facilitated primarily by the ankle joint (Hardaker *et al.*, 1984). Whether the ideal external hip rotation is considered to be 60° or 90°, in comparison to these values, only moderate values of hip external rotation were achieved by the professional dancers in the current study. Thus, although the professionals do exhibit increased external hip rotation compared to the non-professionals, it is interesting that the actual values for active external hip rotation demonstrated by the professionals were relatively low compared to the so called theoretical ideals. Moreover, the review of existing literature reveals that relatively moderate values of external hip rotation have also been reported in previous studies that have used 3D motion analysis to measure hip rotation in classical ballet (Shan, 2005; Wilson *et al.*, 2007; Bronner and Ojofeitimi, 2011). Bronner and Ojofeitimi (2011) analysed the *battement* to the front, side and back of the body, and reported hip rotations at the movement peak of 20° external, 10° internal and 20° external, respectively. Wilson *et al.* (2007) reported external hip rotation angles between 30° and 45° during execution of the *grand rond de jambe en lair en dehors,* and Shan (2005) obtained external hip rotation angles ranging from 0° to approximately 30° during the *grand jeté en avants.* The results for these studies are therefore similar to the current study, in that the hip rotation values are well below the theoretical "ideal" of 60 - 90° external rotation.

Data for ankle transverse rotation are partially in agreement with the theoretical literature. For the start of the steps, professional dancers exhibited an average of 5.3° more external ankle rotation than the non-professionals. This however was not the case when considering the step peaks, or start and peaks combined. For these analyses, mean differences between the groups reduced to only 1.6° and 3.9° degrees, respectively. It was not possible to identify any previously published studies, that used comparable joint movement definitions, to measure ankle external rotation in classical ballet dancers, and therefore comparisons with existing data could not be made.

It is evident that the extent of external ankle rotation achieved is associated with or determined by the sagittal plane motion of the ankle joint at each time point. For example, in all *pliés*, *battements* and *rises*, the ankle is in an approximately neutral sagittal position as the steps commence, and for each of these steps ankle external rotation ranged from 10° to 20°. For the jumping or gliding steps (*i.e. glissades*), in which the dancers commenced (*i.e.* pushed-off) from a position of ankle dorsiflexion, ankle external rotation ranged from 35° to 40°. At the other extreme, steps for which the analysis limb commenced in a position of plantarflexion (*i.e. jetés and pirouettes*), external ankle rotation was very low with values even moving into low ranges of internal rotation. A similar relationship was observed for the step peaks, at which all steps (with the exception of the *pliés*) require maximum plantarflexion, as this occurred in association with ankle rotation values ranging from 4° external to 10° internal. Although reference to the actual values for ankle internal/external rotation has been made, it should be noted that it is the relationship of ankle sagittal plane and transverse plane data that is the point of interest. As indicated in Section 3.2.2.6, the Cardan angle rotation sequence has an effect on the offset of ankle transverse plane rotation data. Consequently, there is uncertainty as to the accuracy of the actual values calculated. Despite this, it is still possible to draw confident conclusions about the difference in ankle external rotation data between groups, and to comment on the relative plantar/dorsiflexion and internal/external rotation that occur concurrently for each ballet step. Although, due to different methodologies, it is not possible to compare the actual values of ankle rotation obtained with those from previous studies, Shan (2005) did report a similar relationship between ankle joint rotation and ankle plantar/dorsiflexion, as that observed in the current study.

Thus, the “forward” or “winged” position, *i.e.* external ankle joint rotation, that has been referred to in the dance literature (*e.g.* “for the preservation of the turnout, the heel is held forward and the toe kept back” (Kostrovitskaya and Pisarev, 1978, p71)) does appear to be better achieved by professional dancers than non-professionals in some instances, and if total ‘turnout’ is considered to be determined by inclusion of the foot progression angle, then ankle rotation does in fact contribute to ‘turnout’ to a greater extent in professional dancers than non-professionals. However, the degree to which external rotation of the ankle joint is biomechanically possible, even for the most highly skilled dancer, is determined by the extent of concurrent plantarflexion or dorsiflexion, and is considerably restricted during positions of extreme plantarflexion.

3.4.4 Extension

Knee joint extension and ankle plantarflexion were the kinematic variables selected to investigate the principle of 'extension', *i.e.* 'maximum elongation of the lower limb'. Data indicate that for all instances when maximum knee extension was required, on average the professional dancers exhibited 3.0° more knee extension than the non-professionals. Analysis of the actual knee flexion/extension values reveals that both groups of dancers demonstrated a sagittal plane knee position beyond neutral, reaching hyperextension for the majority of steps and time points. For the professional dancers, the average knee hyperextension reached 13° in some instances (*e.g.* start of *grand plié in second position*). Comparisons with previous studies is limited by the fact that the majority of other researchers who have measured sagittal plane knee joint motion during ballet movements have been interested in flexion rather than extension (Bronner *et al.,* 2002; Bronner and Ojofeitimi, 2006; Kulig *et al.,* 2011). Shan (2005) was the only study identified that did report on knee joint extension during execution of classical ballet, however differences in the joint angle definitions make it difficult to directly compare data. Thus, comparisons with previous research will not be discussed. However, it is evident that in relation to knee extension, the current data are in agreement with the theoretical principle that highly skilled ballet dancers display extreme elongation ('extension') of their lower limb.

The results for ankle plantarflexion are also consistent with the theoretical principle of 'extension', in that for all steps and time points, professional dancers exhibited more plantarflexion than non-professionals. The general linear model analysis produced significant differences in plantarflexion when considering the step peaks, and starts and peaks combined, but for the step start a significant difference between groups was not found. It should be pointed out, however, that only two steps were included in the analysis of the start, as most steps did not commence with a requirement of maximum plantarflexion. This may have affected the overall result for the analysis of the start time point.

For the professional dancers, mean plantarflexion values ranged from 30° through to 60°. Plantarflexion values were lower when the foot was in a position of *demi-pointe* (*i.e.* standing on the ball of the foot) as in the *rises* and *pirouettes* (30 - 52°), compared to a non weight bearing position with a fully *pointed* foot (53 - 60°). The current data are comparable to results from the limited number of published articles that have used similar techniques to investigate active plantarflexion during execution of classical ballet. Specifically, Lin (2005) used 3D motion analysis to measure maximum ankle plantarflexion during the *relevé en point*, with an average plantarflexion angle of 53° being reported. Thus, as was the case for knee extension, the practical data for ankle plantarflexion are also consistent with the theoretical concept that extreme elongation ('extension') of the lower limb is a characteristic of elite ability in classical ballet technique.

3.4.5 Analysis of Fundamental Principles with Respect to Movement Categories and Steps

Four of the seven movement categories proved most successful in detecting differences between the professional and non-professional dancers in the fundamental principles of classical ballet technique. Specifically, it was the 'bend' (*plié*), 'stretch' (*battement*), 'rise' (*relevé*), and 'turn' (*tour*) categories for which inter-group differences of specific variables were detected. The most commonly detected deviation across these movement categories was for transverse hip rotation, a result that is consistent with the significant difference obtained for this variable through the repeated measures general linear model analyses. The turn (*tour*) category was only sensitive to transverse hip rotation ('turnout') deviations, while the 'rise' (*relevé*) detected differences in both kinematic variables relating to turnout (*i.e.* transverse hip rotation and transverse ankle rotation). It appears that the reduction in contact area between the foot and the floor that occurs during the *rise*, introduces instabilities in stance that provide increased challenge to the maintenance of hip and ankle joint rotation. The *battements* also highlighted differences between groups in transverse hip rotation ('turnout'). This result suggests that movement of a single leg to the front or back of the body can perhaps compromise the ability of the external hip joint rotators to achieve optimal function. In addition, the *battements* also captured differences between groups in knee extension ('extension'). The 'working' leg of the professional dancers reached greater knee hyperextension than that of the non-professionals. The discrepancy between groups in knee extension observed during execution of these steps, but not other steps, suggests that the *battements* are particularly effective in highlighting weaknesses, or lack of use, of the knee extensor musculature.

Finally, the *pliés*, detected differences between groups in thoracic anterior/posterior tilt ('alignment'). That is, the non-professionals demonstrated approximately 5° more anterior thoracic tilt than the professionals at the peak of the movement, *i.e.* at maximum knee flexion. In line with the finding that increased forward trunk lean facilitates increased hip extensor power (Lees *et al.*, 2004; Vanrenterghem *et al.*, 2008), it is possible that as a group the non-professional dancers have weaker hip extensors and are able to access more power for *plié* ascent by increasing hip and trunk flexion during *plié* descent. It has also been shown that increased forward trunk flexion during knee flexion, decreases the torque at the knee joint (Lees *et al.*, 2004), essentially by decreasing the horizontal displacement between the body's centre of gravity and the knee flexion/extension axis. This has the effect of decreasing the load on the knee extensors (*i.e.* quadriceps), a compensation which may be beneficial for the less experienced dancers who may have weaker quadriceps. Therefore, the discrepancies in 'alignment', observed during execution of the *pliés,* may in fact be a reflection of deficiencies in areas other than the trunk itself.

Thus, it appears that there are particular ballet steps or movement categories that are more effective than others in highlighting deviations of certain kinematic variables from the ideal. These deviations may be indicative of biomechanical problems directly related to the area being assessed, or could be compensatory mechanisms due to deficiencies in other areas of the body.

3.4.6 Limitations

3.4.6.1 Limitations of the Biomechanical Model and Measurement Techniques

It is acknowledged that the biomechanical model used in the current study is associated with certain errors and assumptions. For example, as discussed in Section 3.2.3.1, attachment of reflective markers has been shown to be associated with soft tissue artefact (Stagni *et al.*, 2005), and the Vicon Plug-in-Gait model is based on the assumption that the joint structure and body segment proportions of the subjects assessed are in agreement with the anthropometric reference data on which the model is based (Davis *et al.,* 1991). In addition the model was designed specifically for assessment of human gait, rather than for analysis of dance-related movements, which involve much larger ranges of joint motion. In particular, the hip and ankle joint movements required for execution of classical ballet technique are typically beyond that used in normal human gait. However, with respect to the steps that were included in the analyses, examination of the data obtained from performance of multiple ballet steps, indicate that there were no instances of data “flipping” due to “gimbal lock” issues. Gimbal lock describes the discontinuity in data as the second orientation angle reaches +90° or -90° for a Cardan rotation sequence (Lees *et al.*, 2010). In addition, the 3D kinematic values obtained for most of the hip and ankle joint data were reasonable with respect to the movements performed. The one kinematic variable for which data seemed different to that expected was transverse hip rotation. It was noted in Section 3.4.3, that the external hip rotation measures obtained in this study were lower than those that could be expected based on theoretical information. Dance literature states that external hip rotation values ranging from 60-90° are typical for experienced dancers, however the highest mean hip rotation value obtained in this study was only 41°. However, in accordance with the findings of Lees *et al.,* (2010), the Cardan angle rotation sequence was not considered to be influential on the hip rotation data for the steps analysed, and the values obtained were similar to data reported in multiple previous studies that used the same techniques. It is reasonable to suggest therefore, that the data are in fact an accurate reflection of what is actually happening at the hip joint.

It is also acknowledged that the accuracy of marker placement is crucial in determining the accuracy of data obtained from 3D motion analysis. Therefore, to ensure the accuracy and consistency of optimal marker placement across all participants, marker placement was conducted by the same person (the author) for all participants in strict accordance with the Vicon Plug-in-Gait guidelines. Attachment of all knee markers was completed with use of a ‘Knee Alignment Device’ (KAD), thereby adding to the consistency and reliability of the marker placement process. Once all markers were in place, additional accuracy checks were conducted through collection of gait data for each participant, and use of the data accuracy assessment methods typically applied in clinical gait analysis. This included examination of knee varus/valgus data, and comparison with mean data for normal human gait. The fact that this process was conducted adds additional support for the accuracy of the hip rotation data.

In summary, maximum care and effort was taken to ensure optimal accuracy of the kinematic data obtained. In conducting this study, all potential technical limitations were mitigated as much as was practically possible, and therefore any additional issues relating to the equipment or biomechanical model can only be considered to be common to all users of this form of movement analysis, and are therefore not limitations that are unique to this study.

3.4.6.2 Limitations Due to Participant Sample Size

Fourteen non-professional and 12 professional dancers participated in this study. It could be argued that in terms of scientific research studies these are relatively small sample sizes, thus potentially imposing limitations on the conclusions reached. A review of existing literature reporting on biomechanical analysis of dance-related movements (Section 2.2.5.4) revealed that a mean sample size of 10 was obtained across 37 studies. The majority of these studies had less than 15 subjects, with only six studies recruiting between 16 and 25 subjects. In relation to ballet-specific studies, for which recruitment of subjects possessing a highly specialised skill is required, sample sizes ranged from 1 to 16. A review article by Mullineaux *et al.* (2001, p739) states that "in biomechanics research the sample sizes used are often small". They reported a mean sample size of 14.5 participants for research papers published in the *Journal of Biomechanics* in 1998 (Mullineaux *et al.,* 2001). Thus, although the participant sample sizes obtained in the current study were constrained by identification and availability of suitable subjects, and also by practical limitations imposed by restrictions on laboratory and equipment availability, the final sample sizes obtained are well within the ranges of those typically used in biomechanics analysis. Moreover, the relatively low standard deviations, obtained for each group across most steps, indicate that larger sample sizes may not have resulted in vastly different results than those obtained with the current numbers of participants. It should be noted that the few steps for which quite large standard deviations were obtained (*i.e. pirouettes* and *grand jeté elancé en avant*), are some of the more difficult steps in the classical ballet repertoire, and large standard deviations would be expected for any sample size.

3.4.6.3 Limitations Due to Participant Motivation

Another possible limitation that may have affected the data could be the level of personal motivation of the dancers during execution of the steps in the data collection sessions. The technician who conducted all data collection sessions (the author) was not personally familiar with any of the participating dancers, and had not seen them dance prior to their attendance at the biomechanics laboratory. It was therefore not possible to truly know if all dancers exerted maximum effort, and attempted to perform all movements to the best of their ability. All dancers were instructed to perform each step "as best they could", and one would expect that the unusual situation of being inside a laboratory, covered in markers, surrounded by various measurement devices, multiple cameras, and computers would elicit maximum motivation for optimal performance from all dancers. Based on the author's personal observation of the mannerisms, demeanour and body language of all dancers during their motion analysis session, it is believed that all dancers were highly motivated, and did in fact perform to the best of their ability. In addition, the fact that a high degree of consistency of kinematic data between dancers was observed in overlays of time-normalised graphs, indicates that the dancers were executing the steps in accordance with standard classical ballet practice.

3.4.7 Conclusions

Professional ballet dancers perform the fundamental biomechanical principles of 'turnout' and 'extension' in closer agreement with the theoretical principles of classical ballet technique than non-professionals. These theoretical principles therefore accurately reflect what occurs in practice during highly skilled execution of classical ballet technique, and are therefore appropriate guidelines on which to base current teaching practice. However, this is not necessarily the case for the principles of 'alignment' and 'placement'. Interestingly, in relation to 'alignment', ballet dancers adopt posterior thoracic alignment, rather than the vertical alignment referred to in the theoretical literature. In addition, when functionally biomechanically advantageous (*e.g.* when jumping), the 'alignment' of professional dancers deviates from the theoretical ideal more than that of the non-professionals. With respect to 'placement', the pelvic position adopted by ballet dancers is not "neutral" and is not dissimilar to the pelvic position typically used during normal human gait. Although a decreased sagittal plane pelvic range of motion (*i.e.* superior control of sagittal 'placement') shown by professionals is in agreement with the dance literature, in contrast, these more experienced dancers utilise increased coronal and transverse plane pelvic range of motion while performing certain movements. This finding is contradictory to that expected based on theoretical information, and has implications for the instruction of classical ballet technique. The specific implications of these conclusions with respect to classical ballet teaching practice will be discussed in Chapter 6 of this thesis.

This study has also determined that there are particular ballet steps or movement categories that are more effective than others in highlighting kinematic deviations related to the fundamental principles of classical ballet technique. These are the ‘bend’ (*plié*), ‘stretch’ (*battement*), ‘rise’ (*relevé*), and ‘turn’ (*tour*). In Chapter 5, all 14 ballet steps will be further investigated with respect to their ability to detect deviations in kinematic variables, and to rank the technical competency of the group of non-professional dancers against that of the professional dancers (*i.e.* “the gold standard”). To do this, the rank order of the non-professional dancers obtained using different numbers and combinations of ballet steps will be compared. The results from such an analysis could contribute to the development of a quantitative assessment tool to evaluate classical ballet technique. Whether or not such a tool would in fact be necessary ultimately depends on the abilities of dance teachers to qualitatively analysis dance movements. Quantitative biomechanical assessment techniques are typically used (*e.g.* clinical gait analysis) because it is assumed that the accuracy of visual perception is inferior to the accuracy of quantitative data obtained from instrumented techniques (Toro *et al.*, 2003). The ability of experienced and inexperienced ballet teachers to accurately observe, *i.e.* qualitatively analyse, classical ballet movement will therefore be investigated in the next chapter. Ballet teachers’ qualitative responses, obtained through observation of videos of dancers who participated in the current study, will be compared to the quantitative data obtained in the current study.

CHAPTER 4

ACCURACY OF QUALITATIVE ANALYSIS OF CLASSICAL BALLET TECHNIQUE

CHAPTER 4
ACCURACY OF QUALITATIVE ANALYSIS OF CLASSICAL BALLET TECHNIQUE

4.1 Introduction

Movement instructors, such as sports coaches and dance teachers, are faced with many challenges in their efforts to facilitate skill acquisition. The ability to accurately observe learner responses as a precursor to corrective feedback stands as one of the most important operations in motor skill instruction (Imwold and Hoffman, 1983). Without obvious external measures of skill competency, dance students must rely on the observation abilities of their teachers in order to receive useful feedback and correction on the execution of their technique. The effectiveness of a ballet teacher's analysis of the technical abilities of their students is based firstly upon having a thorough knowledge of the fundamental principles upon which the movement technique is based, and secondly on the accuracy with which they can see the movement patterns executed by their students. Having a clear and detailed understanding of the ideal or desired movement pattern for each skill enables the instructor to develop an internally held criterion or mental image of the desired execution of the movement (Whiting, 1972).

When analysing the movement patterns or responses of their students, motor skill instructors need to be able to form a mental image of the desired response and compare that image with the learner's response during immediate observation. Once the nature and extent of any deviation of the learner's response from the desired response is identified, teachers can then provide appropriate feedback and instruction to their students. This whole process has been defined as "qualitative analysis" and has been described as the "systematic observation and introspective judgment of the quality of human movement for the purpose of providing the most appropriate intervention to improve performance" (Knudson and Morrison, 1997, p4). Other terms such as movement analysis, clinical diagnosis, skill analysis, error detection, observational assessment, systematic observation, and introspective judgement have also been used in the same context (Knudson and Morrison, 1997), but for the purposes of this study the term “qualitative analysis” will be used.

Not only is the skill of qualitative analysis of human movement important for motor skill acquisition, but it also plays a vital role in injury prevention. Poor technique is an important risk factor for the development of overuse injuries in classical ballet, as well as many other forms of skilled movement. If deficiencies in technique can be identified immediately and corrected, then the risk of injury can be reduced or prevented. The accuracy with which an instructor can see the motor response of their students, and thus determine how it deviates from the desired or ideal response, is therefore crucial for many aspects of successful motor skill instruction.

It has been suggested that humans may have special perceptual abilities relating to the analysis of human motion, which may extend beyond the kind of data obtained from pure quantitative analysis (Morrison, 2000). The implicit assumption is that people who regularly use the skill of qualitative analysis, such as dance teachers, sports coaches, clinicians and ergonomists, have the ability to observe motor skill performances systematically and critically and to identify flaws accurately. Whether this is actually the case has been the subject of studies in the clinical setting, by some in the fields of ergonomics and workplace safety, and by a few in the sporting arena (Section 2.3.4). However, the accuracy with which dance teachers can visually observe their students’ movement patterns, and identify correct or incorrect technique, has received no attention in the academic literature to date. It has been stated (Imwold and Hoffman, 1983) that neglect of this topic by researchers may retard the design and implementation of training programs for movement teachers who, without access to such programs, will be forced to train themselves through the random events of day-to-day teaching. Left to their own devices, and given sufficient time and experience, some movement teachers and coaches may develop competency in qualitative analysis, however it has been proposed (Arend and Higgins, 1976) that the teacher who is a trained analyser of human movement will be better equipped to enhance the process of skill acquisition than the teacher who has not received specific training in the process.

Many professional dancers retire from their performing career and immediately commence teaching dance. It seems to be an accepted belief that a highly accomplished dancer will instantly have the skills required to be a highly effective teacher. However, this may not necessarily be the case in that an expert level of practical ability in a movement discipline may not necessarily be accompanied by a high level of cognitive ability in identifying and articulating the theoretical principles and corrections that are crucial for successful execution of skilled movement. Thus, it may be that some ballet teachers are deficient in their qualitative analysis skills and could benefit from specific training in this area. This study therefore aims to investigate the accuracy with which ballet teachers are able to qualitatively assess the technique of classical ballet dancers. The ability of ballet teachers to identify “correct” and “incorrect” classical ballet technique will be assessed, and analysed with respect to their level of experience in classical ballet teaching, their ballet training history, and their professional performance experience. Measures of accuracy will be obtained by comparing qualitative assessments with quantitative data obtained from 3D motion analysis data.

It has been stated (Runeson, 1984) that if perceptual observation can be identified as a skill, then it might be anticipated that more experienced teachers should have an improved ability to detect the significant features in technical execution of a movement. Thus, the primary hypothesis is that experienced ballet teachers will more accurately recognise the occurrence of correct and incorrect classical ballet technique, and more accurately determine the type of correction required to improve incorrect technique. A secondary hypothesis is that experienced ballet teachers will be more accurate in determining which body region contributes most significantly to the execution of incorrect ballet technique.

4.2 Methods

4.2.1 Participant Recruitment

Professional and student ballet teachers were recruited to take part in the study. Prior to commencing the recruitment process, ethics approval was obtained through the University of New South Wales Human Research Ethics Advisory (HREA) Panel (Appendix J). The target number of subjects for recruitment to the study was 20 student ballet teachers and 20 professional ballet teachers.

Criteria for inclusion as a student ballet teacher were,

- being at least 18 years of age at the time of data collection
- never having been employed as a professional ballet teacher.
- being currently enrolled in a dance teacher training program.

For recruitment of the student ballet teachers, second year students enrolled in the University of New South Wales Bachelor of Arts (Dance)/Bachelor of Education program were invited to attend an information session held on the university campus, during which information was provided about the project. This session was facilitated with the assistance of the program authority. During this session, potential participants were informed of the inclusion criteria for participation in the student teacher group, and were provided with information on what they would be required to do as study participants, and how their data would be used for the study. Interested potential participants provided their name and contact details at the end of the session, and were subsequently emailed an information and consent form prior to attending a data collection session.

Inclusion criteria for participation as a professional ballet teacher were,

- being at least 18 years of age at the time of data collection.
- being employed as a professional ballet teacher at the time of data collection, or within the 12 months preceding time of data collection.

The professional ballet teachers were recruited from various ballet schools around the Sydney metropolitan area. Recruitment of professional ballet teachers occurred via emailing and calling administrative staff at local dance schools, by distributing information flyers throughout dance schools, by giving brief presentations at dance teacher seminars, and by contacting dance teachers on an individual basis as identified by word-of-mouth within the Sydney dance community.

Upon identification of potentially suitable and interested participants for the professional group of teachers, all potential participants were informed of the inclusion criteria for participation in the professional group, and were emailed detailed information on what they would be required to do as study participants and how their data would be used for the study. Each participating professional teacher was given an information and consent form prior to their data collection session.

All subjects provided written informed consent, in the form of a signed and dated consent form (Appendices K and L), prior to commencing any data collection for the study. No form of incentive or compensation was offered or provided to any student or professional teachers for their participation in the study.

4.2.2 Development of the Qualitative Assessment Questionnaire

The qualitative assessment questionnaire was comprised of 40 multiple choice questions. It consisted of eight questions for each of the five steps selected for qualitative analysis. The same eight questions were asked for each step. The questionnaire was presented to the participants in the form of a Microsoft PowerPoint® presentation.

The questionnaire was developed through careful consideration of the existing academic literature that has investigated the accuracy of qualitative analysis of human movement. That is, through conducting the literature review, described in Section 2.3, a number of findings and conclusions from previous studies provided useful information that assisted in designing the type of questions, and the number and type of scale categories.

The majority of questions in the Qualitative Assessment Questionnaire related to identification of “correct” or “incorrect” classical ballet technique. The first question for each step required the teachers to observe the whole body and to indicate which body region, if any, was most in need of correction. This style of question was chosen for inclusion as it did not direct the teachers to focus on any one specific body area, and thus provided an opportunity to assess and compare which technical aspects of classical ballet teachers are most concerned with when allowed to perform non-directed qualitative analysis. The remaining questions for each step provided more specific direction as to which body region to observe. Data from the academic literature indicate that better accuracy of observation is achieved when the number of parameters an analysts is required to observe is kept to a minimum, ideally limited to only one or two. Thus, each remaining question for each step directed the participating teachers to only observe movement at one body segment or joint and in only one plane of movement. The four different segments or joints chosen for inclusion were thoracic anterior/posterior tilt, pelvic anterior/posterior tilt, hip external rotation, and knee extension. Each of these regions related to one of the four fundamental principle of classical ballet technique (*i.e.* 'alignment', 'placement', 'turnout', 'extension'), as outlined in Section 2.1.

As was indicated through review of the existing academic literature, better accuracy of qualitative analysis is obtained when categorical scales containing fewer categories are used, and when categories are adequately labelled with appropriate references to the skill level or normality. For these reasons, binary categorical scales were used for each of the questions relating to a specific body region. Although the academic literature did indicate that in clinical practice better accuracy of observation is achieved when joint range categories as well as appropriate labels are included on the scale, it was decided to only use labels, and these were in the form of references to "correctness" of technique. This decision was based on the fact that, unlike physiotherapists, dance teachers do not typically observe and refer to joint ranges of motion in specific numerical terms, so this form of categorising would not have been familiar to the majority of participating teachers. Therefore, for each of the four individual parameters chosen for inclusion in the questionnaire, teachers were asked to identify if movement at the joint/segment was "correct" or "incorrect" with respect to their own knowledge of classical ballet technique. It should be noted that teachers were not instructed as to what constituted "correct" or "incorrect" technique before or during any of the data collection sessions.

In addition to identifying "correct" or "incorrect" technique for each individual parameter for each step, participants were also asked to indicate which type of correction might be required to correct incorrect technique. That is, if a participant selected the "incorrect" category for a particular movement parameter, they were then presented with an additional question, which they were required to answer through use of another binary scale containing two categories of possible corrections.

A copy of the Microsoft PowerPoint® presentation format used to present the Qualitative Assessment Questionnaire, and an example of the questions for a single step are presented in Appendix N.

4.2.3 Video Data Selection and Preparation

After selecting the type and number of questions that would be included in the Qualitative Assessment Questionnaire, a selection of dance videos were chosen for inclusion in the data collection sessions. The same videos were viewed by all participating teachers in all sessions. Five videos, consisting of five different ballet dancers performing five different ballet steps were selected. Each of these dancers had participated in the motion analysis section of the study (described in Chapter 3) in which simultaneous video and 3D motion analysis data were obtained for each dancer performing steps from each of the 'Seven Movements of Dance' (Noverre, 1760). All dancers who participated in this section of the study provided written consent for their video data to be watched by ballet teachers participating in the current section of the study.

As indicated in the academic literature, when conducting video-based qualitative analysis the position of the camera in relation to the plane of joint motion has a significant effect on the accuracy of observation. Specifically, better accuracy is achieved when the direction of the camera and the plane of joint motion are orthogonal. Authors have suggested that use of multiple cameras placed at various perspectives is therefore advantageous in optimising accuracy of observation. Each video therefore consisted of a dual perspective view of the dancer (Figure 4.1), in which frontal and sagittal plane aspects were simultaneously played to the viewer. This setup was considered to provide the observer with maximum opportunity to accurately view all relevant parameters.

Figure 4.1 *Example of sagittal and frontal views played simultaneously for all videos.*

All video footage was obtained in the same laboratory with the same recording equipment (two Sony digital camcorders), and all dancers wore the same dance clothes in all videos (*i.e*. black bike shorts, black crop top, and Bloch foot thongs). The accompanying music, to which all dancers performed the steps during the motion analysis sessions, was not audible to the viewers during the qualitative observation sessions. Each video was edited so that the start and finish of the step corresponded to the start and finish as defined by the Visual Basic macros described in Chapter 3 of the thesis. All edited videos were inserted into a Microsoft PowerPoint® presentation that was presented to all participating teachers during the qualitative analysis data collection sessions.

The five videos selected for inclusion in the qualitative analysis data collection sessions were chosen such that each video contained footage of a different dancer performing a step from one of five different movement categories. These five categories were:

- Bend (*plié*)
- Rise (*relevé*)
- Stretch (*battement)*
- Turn (*pirouette*)
- Jumps (*sauté*)

Videos of steps in the glide (*glissé*) and dart (*elancé*) movement categories were not included in the qualitative analysis data collection sessions. This was due to the fact that the travelling nature of these movements meant that the dancers moved in and out of view of the stationary cameras throughout the execution of the movement. It was therefore not possible to obtain a clear, full body frontal and sagittal view of these steps, and they were consequently omitted from the analysis. The specific steps chosen for inclusion in the qualitative analysis are listed in Table 4.1.

In assembling the final list of videos included in the qualitative analysis sessions, it was not only necessary to choose a combination of five videos that represented each of the five different movement categories, as listed above, performed by five different dancers, but it was also important that the selection of videos contained approximately equal numbers or "correct" and "incorrect" kinematic variables. It was important to choose five different dancers to ensure that participating teachers would not become familiar with the individual movement patterns or habits of any one dancer throughout the analysis session, thereby reducing the likelihood of any learning effect occurring as the session progressed. An equal spread of "correct" and "incorrect" kinematic variables across the five videos was necessary so that the incidence of any Type I and Type II Errors could be analysed. Type I Errors occur when a "null hypothesis is rejected when it is really true", while a Type II Errors occur when a "null hypothesis is accepted when it is really false" (Vincent, 1995, p248). In the context of the current study, a Type I Error would be a situation where correct ballet technique is rated as "incorrect", and a Type II Error would occur if incorrect ballet technique is rated as "correct".

In terms of the kinematic variables that participants were asked to observe during the analysis sessions, these were selected so as to align with the four fundamental biomechanical principles of classical ballet technique, as identified in Chapter 2 and analysed in Chapter 3. In order to maintain consistency in the way in which the steps were observed, the same four kinematic variables were selected for analysis for each step. Thus, in observing each of the five steps, participants were required to rate the dancer's technique in terms of each of the four fundamental biomechanical principles of classical ballet technique, with each of these principles relating to a different body region.

4.2.3.1 Measurement of Response Accuracy: Calculation of Quantitative Reference Criteria

As described in Section 4.2.2, participants were asked a number of questions which required them to focus on individual body regions, rather than on the whole body. For each separate body region, in answering the question "*does the body region need correction?*", participants were required to select one of two options, "yes" or "no". In order to identify whether or not respondents were accurate in answering this question, it was necessary to establish objective quantitative reference criteria against which all qualitative responses could be compared, and thus identified as either "accurate" or "inaccurate". The videos that were chosen for inclusion in the qualitative observation sessions were therefore selected according to their accompanying kinematic data, obtained from simultaneous 3D quantitative motion analysis. That is, in order to make a final selection of the videos for inclusion in the study, it was necessary to assess how the kinematic data for individual dancers compared to the mean data for the professional group of dancers. To make this comparison, z-scores were calculated to compare joint and segment movement patterns of individual dancers with mean values of the "gold standard data", *i.e.* mean joint angle data for the groups of professional ballet dancers.

The z-score is a standard score expressed in terms of standard deviation units on a normal curve (Hastad and Lacy, 1994). This value indicates how far above or below the group mean the raw score is located. The further above the mean the raw score is, the higher the z-score will be. If the raw score is below the mean the z-score will be negative, and will increase in magnitude the further below the mean the raw score is located. If a raw score is exactly the same as the group mean it will have a z-score of zero. The z-score for an individual value is calculated using the group mean and standard deviation, according to the following formula:

$$z = \frac{\bar{x}-x}{s}$$

where $\bar{\chi}$ = group mean, χ = raw score , and s = standard deviation.

For the purposes of systematically and objectively identifying whether or not each kinematic variable for each step for each dancer required correction, an absolute z-score of 1 was chosen as the cut-off point or threshold above which the variable should be rated as “incorrect”, and thus in need of correction. That is, a z-score of 1.0 indicates that a raw score is 1 standard deviation above the mean, while a z-score of -1.0 indicates that a raw score is 1 standard deviation below the mean. In any normal distribution curve, 68.26% of all data falls between the mean and ±1 standard deviation from the mean (Vincent, 1995). Therefore, a cut-off value of ±1 standard deviation (*i.e.* a z-score within the range -1 to 1) allows a large range within which the majority of data for the population in question falls. Thus, in using the 3D kinematic data to rate the technical performance of each dancer, an objective system was put into place in which any kinematic variable with a z-score greater than 1.0 or less than -1.0 was deemed to be “incorrect”, and therefore in need of correction. Any variable whose z-score fell in the range $-1.0 < 0 < 1.0$, was labelled as “correct”, and therefore not in need of correction. Previous studies (Nicholls *et al.*, 2003; Moseley *et al.*, 2008) have reported the same method for determining “proper” or “improper” sports technique (Nicholls *et al.*, 2003) or “flexible” or “inflexible” ankle movement (Moseley *et al.*, 2008). The magnitudes of the absolute value of the z-scores were therefore used for determination of whether a kinematic variable was “correct” or “incorrect”, and therefore provided the reference criteria used to determine whether respondents were “accurate” or “inaccurate” in assessing the dancers’ technique. Table 4.1 lists the ballet steps that were chosen for qualitative analysis, the movement category each step falls into, the kinematic variables chosen for observation and their associated fundamental principle, the mean z-score for each kinematic variable for each step, and whether the variable was determined to be “correct” or “incorrect”. The total number of “correct” and “incorrect” kinematic variables are also listed.

Kinematic Variable	**Step**					
	Grand Plié in First Position **(Bend)**	*Rise in Second Position* **(Rise)**	*Grand Battement Derriere 90°* **(Stretch)**	*Double Pirouette En Dedans* **(Turn)**	*Temps Levé* **(Jump)**	
Subject ID	PR007	PR010	PR001	PR005	PR002	
Thorax anterior/posterior tilt (Principle = Alignment)	-1.17 (×)	-1.35 (×)	-1.20 (×)	-0.21 (✓)	1.53 (×)	
Pelvis anterior/posterior tilt (Principle = Placement)	1.01 (×)	1.53 (×)	-1.35 (×)	0.15 (✓)	-1.31 (×)	
Hip rotation (Principle = Turnout)	-0.17 (✓)	1.38 (×)	-0.49 (✓)	-0.59 (✓)	0.36 (✓)	
Knee flexion/extension (Principle = Extension)	-0.23 (✓)	-1.37 (×)	1.33 (×)	0.22 (✓)	0.64 (✓)	
						Total
Total Correct Technique	2	0	1	4	2	**9**
Total Incorrect Technique	2	4	3	0	2	**11**
Total	**4**	**4**	**4**	**4**	**4**	**20**

Table 4.1 *Mean z-score for each step for selected kinematic variables observed during qualitative analysis data collection sessions. (×) = Incorrect technique; (✓) = Correct technique*

If participants responded with an answer of "*yes*" to the question "*does the body region need correction?",* they were then asked "*which type of correction is required?*" An objective reference criterion for this question was determined according to the sign of the z-score. For a kinematic variable with a z-score of less than -1.0, the required correction would be towards the positive direction, and for a z-score of more than 1.0, the required correction would be towards the negative direction. For example, as shown in Table 4.1, in her performance of the *grand plié in first position*, subject PR007 obtained a z-score of -1.17 for thoracic anterior/posterior tilt. For this variable, a negative value for the raw data indicates that the dancer's thorax is in posterior tilt, and a positive value indicates anterior tilt. Therefore, a z-score of -1.17 indicates that the dancer's thorax was posterior compared to the professional group mean by more than one standard deviation, and this dancer should therefore be corrected to shift her thorax into a more anterior position.

Another question on the qualitative assessment questionnaire required the participants to observe the dancers' whole body during performance of the ballet movement, rather than focusing on individual body segments. Specifically, participants were asked to answer the question "*if you could give this dancer only one correction on their execution of this step, which body region would you concentrate on correcting?*". Participants were required to give their answer by selecting one of seven multiple choice options, as outlined below;

1. Thorax (upper torso)
2. Pelvis
3. Hips
4. Knees
5. Ankles/Feet
6. Other
7. None – No correction required

The "correct" answer for each step, based on a quantitative reference criterion, was determined by calculation and comparison of the mean z-score across each step, for each plane of motion (sagittal, frontal, transverse) for the thorax, pelvis, hip, knee, and ankle. The kinematic variable with the largest absolute value for the z-score was identified as the variable most in need of correction, and was therefore determined to be the "correct" answer. The respondent's answer selection was compared to this variable in order to determine whether they were "accurate" or "inaccurate" in answering this question. Table 4.2 displays the mean z-scores for each kinematic variable for each step, and indicates which variable was identified quantitatively as being "most in need of correction".

Participants were not asked to provide so much detail as to indicate which plane of joint or segment motion was most in need of correction, but only which body region. Answers were therefore considered to be "accurate" if the selected body region matched the quantitative reference criteria, regardless of the plane of motion.

Kinematic Variable	**Step**				
	Grand Plié in First Position **(Bend)**	*Rise in Second Position* **(Rise)**	*Grand Battement Derriere 90°* **(Stretch)**	*Double Pirouette En Dedans* **(Turn)**	*Temps Levé* **(Jump)**
Subject ID	PR007	PR001	PR010	PR005	PR002
Thorax Anterior/Posterior Tilt	-1.17*	-1.20	-1.35	-0.21	1.53
Thorax Side Tilt	0.58	-0.62	-0.34	0.39	-0.71
Thorax Rotation	0.23	0.05	0.48	-0.53	0.01
Pelvic Anterior/Posterior Tilt	1.01	-1.35	1.53*	0.15	-1.31
Pelvic Obliquity	0.01	1.27	-0.08	-0.35	-1.86*
Pelvic Rotation	0.87	1.20	-0.83	-0.55	-1.23
Hip Flexion/Extension	0.11	-0.73	1.18	0.00	-0.52
Hip Abduction	0.08	-0.77	-0.07	-0.72	-1.64
Hip Rotation	-0.17	-0.49	1.38	-0.59	0.36
Knee Flexion/Extension	-0.23	1.33	-1.37	0.22	0.64
Knee Rotation	0.17	-0.24	-0.65	0.31	0.27
Knee Varus/Valgus	0.31	1.38	-1.22	0.89	0.02
Ankle Dorsi/Plantarflexion	-0.35	1.52*	-0.97	0.44	0.44
Ankle Inversion/Eversion	0.33	1.40	1.40	-0.19	-0.77
Ankle Rotation	0.24	-1.07	1.37	-0.54	0.43
Largest absolute z-score	*1.17*	*1.52*	*1.53*	*0.72*	*1.86*
**Kinematic variable with largest z-score (i.e. variable most in need of correction)*	*Thorax Anterior/ Posterior Tilt*	*Ankle Dorsi/ Plantarflexion*	*Pelvic Anterior/ Posterior Tilt*	*None* *(all < |1|)*	*Pelvic Obliquity*

Table 4.2 *Mean z-scores for all kinematic variables for all steps observed during qualitative data collection sessions.*

4.2.4 Experimental Protocol

All participating student teachers attended a single qualitative analysis data collection session. This was conducted on the UNSW campus. Professional teachers were more restricted in their availability, so multiple data collection sessions, consisting of one to three participants, were scheduled across a number of weeks in order to accommodate the limited availability of these participants. All sessions for professional teachers were also conducted on the UNSW campus.

At the beginning of each session, before collecting any data, a signed and dated consent form was obtained from each participant (Appendices K and L). Participants were then asked to complete a “Ballet Teacher Questionnaire”. This form consisted of 40 questions asking information about the participants’ date of birth, dance training history, dance performance history, teacher training history, teacher employment history, and anatomy and biomechanics training history. Participants spent 10-15 minutes completing this questionnaire. A copy of the questionnaire is presented in Appendix M.

After collecting all completed consent forms and questionnaires the qualitative analysis data collection began. This session consisted of an introductory speech, given by the author, in which the terminology that would be used in subsequent questions was clarified, and participants were given instructions on the procedure that would take place. All instructions were displayed in writing as part of a Microsoft PowerPoint® presentation, with accompanying verbal instruction also being provided. Subjects were informed that they would be shown five videos, and would be asked to answer the same eight questions for each of the videos. It was emphasised to all participants that they were only required to focus on technical aspects of the dancers’ execution of the steps, as this study was not addressing overall performance elements such as artistry and presentation. Subjects were also told that they were free to withdraw from the study at any time during the data collection session if they so desired. Participants were given an opportunity to ask any questions before presentation of the videos began.

All videos, questions and answer options were presented to the participants in the form of a Microsoft PowerPoint® presentation (Appendix N) projected onto a large screen at the front of a university tutorial room. Subjects sat comfortably at desks at a self selected distance from the screen. For each of the eight questions for all five ballet steps, the participants were firstly shown the question and possible answer options, and were then shown the video. After watching the video, the subjects were shown the question and answer options again, and were asked to select the answer option they felt was most appropriate. Participants responded to questions by selecting the desired answer number through use of a hand held remote control device (ResponseCard® keypads), and associated hardware (TurningPoint® USB receiver device) and software (TurningPoint® 2008 v4.1).

Each qualitative analysis data collection session took approximately 45 minutes to complete. Upon completion of each session, the captured data were exported to a Microsoft Excel® spreadsheet, through use of TurningPoint® software (TurningPoint® 2008 v4.1), and saved for subsequent analysis.

4.2.5 Data Analysis

Measures of accuracy of qualitative assessment of classical ballet technique were obtained by comparison of subjects' qualitative responses with quantitative 3D kinematic data, as described in Section 4.2.2. Measures for accuracy of qualitative assessment for each type of question in the qualitative assessment questionnaire were calculated as a value of "percentage accuracy".

4.2.5.1 Accuracy of Identification of the "Body Region most in need of Correction"

All participants responded to five questions, one for each step, in which they were asked to identify which body region, if any, was most in need of correction. Participants gave their responses by selecting one of seven possible answer options. A figure for overall "percentage accuracy" for this question was therefore calculated by combining the response to this question for all five step. Since participants were asked the same question for all five steps, the accuracy of responses for was also analysed with respect to the step observed.

4.2.5.2 Accuracy of Identification of "Correct" or "Incorrect" Technique

Each participant responded to a total of 20 questions in which they were asked to rate the dancer's technique as "correct" or "incorrect", one question for each of the four different body regions for each of the five steps. The figure for overall "percentage accuracy" for this type of question was therefore calculated by combining responses for all body regions for all steps. In addition, the proportions of Type I and Type II errors, and measures of sensitivity and specificity were calculated for each group. Sensitivity and specificity are closely related to the concepts of Type I and Type II errors, and are measures of the performance of a binary classification test (Loong, 2003). Sensitivity measures the proportion of positives results (*i.e.* for this study "incorrect technique") which are accurately identified, while specificity measures the proportion of negative results (*i.e.* “correct technique”) which are accurately identified.

4.2.5.3 Accuracy of Identification of “Type of Correction Required”

If a participant identified that the technique for a particular body region for a particular step was “incorrect”, they were then asked to identify *“which type of correction is required”* to correct the technique. Subjects answered this question by selecting one of two answer options, *e.g.* segment (thorax/pelvis) needs to move anterior (forwards) or posterior (backwards). A “percentage accuracy” score was calculated for each subject, based upon the number of variables they had identified as “incorrect”, and the proportion of these that were answered accurately. The total number of applicable responses to this type of question could therefore potentially be different for each subject, depending upon the number of kinematic elements they considered to be incorrect.

4.2.6 Statistical Analysis

The effect of professional ballet teaching experience on the accuracy of qualitative assessment of classical ballet technique, data were analysed in terms of two categories of subjects.

- Group 1: Student ballet teachers
- Group 2: Professional ballet teachers

4.2.6.1 Accuracy of Identification of the “Body Region most in need of Correction”

Binary logistic regression was used to statistically assess the accuracy of identification of “which body region was most in need of correction”. Since in answering this question the participants were required to observe the whole body, rather than being directed to observe individual body segments, these data were analysed separately from the data relating to single body regions. The two categories for the dependent binary variable of “accuracy” were “yes” and “no”. These data were analysed in terms of professional teaching experience using the two categories of the independent variable “teaching experience”, as listed above.

4.2.6.2 <u>Reliability of Identification of the "Body Region most in need of Correction"</u>

The inter-rater reliability of identification of "which body region was most in need of correction" was determined by calculating percentage agreement (P_o) and Randolph's *kappa* (*k*) values (Randolph, 2005; Randolph, 2008). Unlike Cohen's *kappa*, which only allows comparison between two raters, Randolph's *kappa* enables calculation of reliability of observations between multiple raters (Warrens, 2010). *Kappa* data for each group were interpreted and assigned a reliability rating based on the guidelines provided by Landis and Koch (1977).

K value	Interpretation
< 0	Poor agreement
0.01 – 0.20	Slight agreement
0.21 – 0.40	Fair agreement
0.41 – 0.60	Moderate agreement
0.61 – 0.80	Substantial agreement
0.81 – 1.00	Almost perfect agreement

Table 4.3 *Kappa value ranges and interpretation (from Landis and Koch 1977, p 165)*

4.2.6.3 <u>Accuracy of Identification of "Correct" or "Incorrect" Technique</u>

To compare the accuracy of qualitative assessment of "correct" or "incorrect" technique for individual body regions, binary logistic regression was also used. The two categories for the dependent binary variable of "accuracy" were "yes" and "no". A result of "yes' was achieved for "accuracy" if a correct kinematic variable was rated as "correct", or if an incorrect kinematic variable was rated as "incorrect". If either a Type I Error (correct technique rated as "incorrect"), or a Type II Error (incorrect technique rated as "correct") occurred, then a result of "no" was obtained for "accuracy". The independent variables examined via binary logistic regression were the two categories of professional ballet teaching experience, as listed above.

In addition, two separate regression models were run to test for the effect of teaching experience on the occurrence of Type I and Type II errors. One model contained accuracy data for variables for which no correction was required (*i.e.* variables for which a Type I Error could be obtained), and the other model contained variables for which a correction was required (*i.e.* variables for which a Type II Error could be obtained). Both regression models contained one independent categorical variable, years teaching experience, and a binary dependent variable of "accuracy", with two possible options of "yes" or "no".

To further assess the effect of the number of years of professional teaching experience, on the accuracy of qualitative assessment, the percentage of accurate responses was calculated for each professional teacher, and then linear regression was performed against the number of years of professional teaching experience.

For the professional teachers who were at least 24 years of age (*i.e.* those of an age at which they could have completed at least 6 years of professional performance experience as a classical ballet dancer), independent sample t-tests were conducted to check for differences in mean "percentage accuracy" for the following sub groups:

- Ex-professional ballet dancer versus non ex-professional ballet dancer
- Completed teacher training course versus did not complete teacher training course

4.2.6.4 <u>Accuracy of Identification of "Type of correction required"</u>

Binary logistic regression was also used to test for a statistically significant effect of the independent variable, "ballet teaching experience", on the accuracy of response to *"which type of correction is required"*. The binary dependent variable was "accuracy" with two possible options of "yes" or "no", and again the categorical independent variable examined was the two categories of professional ballet teaching experience, as listed above.

4.3 Results

4.3.1 Participant Demographics

A total of thirty five professional and student dance teachers volunteered to participate in the study, all 35 participants completed all data collection requirements. Of these recruited participants, 19 were student teachers enrolled in the University of New South Wales Bachelor of Arts (Dance)/Bachelor of Education program, and 16 were professional ballet teachers recruited from local dance schools. Upon review of the participant information questionnaires, data from 2 participants were excluded from the study. One student teacher from UNSW had received significantly less ballet training (1.5 years) compared to all other participants (mean 14.0 years: SD 2.6 years), and was excluded on these grounds, while one professional teacher with 20 years experience described herself primarily as a Pilates teacher rather than a ballet or dance teacher. Pilates and ballet are different movement disciplines, with differing criteria on which technical skill and competency are based, the data from this participant were therefore also excluded from the study.

On synthesising and reviewing the subject demographic data, it became apparent that rather than assigning participants to one of two groups (*i.e.* student ballet teachers and professional ballet teachers) as originally intended and outlined in the methods section, it would actually be more appropriate to assign participants into three different groups. Six of the student teachers listed on their questionnaire that they had already had some professional experience in classical ballet teaching (1 – 4 years), and the range of experience listed by the professional ballet teachers was very broad (2 – 33 years). It was therefore decided to divide the participant data into three groups based on years of professional ballet teaching experience. Therefore, data obtained from each of the 33 recruited teachers included in the analysis were placed into one of three groups, categorised as follows:

- Group 1: 0 years ballet teaching experience
- Group 2: 1 to 9 years ballet teaching experience
- Group 3: Greater than 10 years ballet teaching experience

Group 1 consisted of 12 participants, all of whom were student dance teachers enrolled at UNSW who were yet to work professionally as classical ballet teachers. Group 2 contained a total of 11 participants, 6 of whom were student dance teachers enrolled at UNSW who listed that they had worked for between 1 and 4 years as professional ballet teachers, and 5 participants were professional ballet teachers, with ballet teaching experience ranging from 2 to 9 years. Ten professional ballet teachers were assigned to Group 3, their professional ballet teaching experience ranged from 10 to 33 years.

Group	**0 Years Ballet Teaching Experience (N=12)**	**1-9 Years Ballet Teaching Experience (N=11)**	**≥10 Years Ballet Teaching Experience (N=10)**
Years professional ballet teaching experience (mean ± SD) *	0.0 ± 0.0	3.9 ± 2.8	18.1 ± 8.2
Total years ballet training (mean ± SD)	14.0 ± 2.8	15.3 ± 1.8	12.7 ± 2.8
Years employed as professional ballet dancer (mean ± SD) *	0.0 ± 0.0	1.1 ± 2.4	4.6 ± 6.0
Age in years (mean ± SD) *	19.7 ± 1.1	23.5 ± 5.5	44.9 ± 10.0

Table 4.4 *Participant demographics. *ANOVA (p<0.05)*

A oneway ANOVA was conducted to test for statistical differences in demographic data between groups. Statistical differences were observed between groups for years professional teaching experience ($F = 42.70$; $p = 0.000$), years employed as a professional ballet dancer ($F = 4.804$; $p = 0.015$), and age ($F = 48.17$; $p = 0.000$). Statistically significant differences were not observed between groups for total years ballet training ($F = 2.610$; $p = 0.090$).

Since the total years of ballet training was not significantly different between groups, the effect of this variable on accuracy of qualitative analysis of classical ballet technique cannot be investigated in this study, and will therefore not be included in any statistical analyses.

4.3.2 Accuracy and Reliability of Identification of the "Body Region Most in Need of Correction"

On their initial viewing of each step, participants were asked to answer the following question:

"*If you could only give this dancer one correction on the execution of this step, which body region would you concentrate on correcting?*

Frequency of responses for each body region for each step for Groups 1-3 are presented in Tables 4.5 – 4.7, respectively. The percentage of accurate responses for each step and the overall percentage accuracy for all steps combined is also presented.

Step **(Accurate Response)**	**Answer Options**							**Total**		**% Accurate Responses**
	Thorax	**Pelvis**	**Hips**	**Knees**	**Ankles/ Feet**	**Other**	**None**			
Grand Plié in First **(Thorax)**	**0***	2	1	1	5	0	3	12		0%
Rise Second **(Pelvis)**	6	**2***	1	0	1	1	1	12		17%
Grand Battement Derriere **(Ankles/Feet)**	3	2	1	2	**1***	2	1	12		8%
Double Pirouette En Dedans **(None)**	0	5	0	0	2	1	**4***	12		33%
Temps Levé **(Pelvis)**	5	**2***	0	1	3	0	1	12		17%
Total for All Steps	14 (23%)	13 (22%)	3 (5%)	4 (6%)	12 (20%)	4 (6%)	10 (17%)	**60 (100%)**		**15%**

Table 4.5 *Response counts for Group 1 (Teaching Experience = 0 years) (N = 12)*
****Accurate response.***

Step **(Accurate Response)**	**Answer Options**							**Total**		**% Accurate Responses**
	Thorax	**Pelvis**	**Hips**	**Knees**	**Ankles/ Feet**	**Other**	**None**			
Grand Plié in First **(Thorax)**	**2***	2	1	3	2	0	1	11		18%
Rise Second **(Pelvis)**	4	**2***	1	1	1	0	2	11		18%
Grand Battement Derriere **(Ankles/Feet)**	5	2	1	0	**1***	1	1	11		9%
Double Pirouette En Dedans **(None)**	1	3	0	2	0	0	**5***	11		45%
Temps Levé **(Pelvis)**	6	**1***	1	3	0	0	0	11		9%
Total for All Steps	18 (33%)	10 (18%)	4 (7%)	9 (16%)	4 (7%)	1 (2%)	9 (16%)	**55 (100%)**		**20%**

Table 4.6 *Response counts for Group 2 (Teaching Experience = 1-9 years) (N = 11)*
**Accurate response.*

Step **(Accurate Response)**	**Answer Options**							**Total**		**% Accurate Responses**
	Thorax	**Pelvis**	**Hips**	**Knees**	**Ankles/ Feet**	**Other**	**None**			
Grand Plié in First **(Thorax)**	**1***	5	0	1	3	0	0	10		10%
Rise Second **(Pelvis)**	2	**7***	0	0	0	1	0	10		70%
Grand Battement Derriere **(Ankles/Feet)**	7	2	0	1	**0***	0	0	10		0%
Double Pirouette En Dedans **(None)**	1	5	0	0	1	1	**2***	10		20%
Temps Levé **(Pelvis)**	5	**4***	0	1	0	0	0	10		40%
Total for All Steps	16 (32%)	23 (46%)	0 (0%)	3 (6%)	4 (8%)	2 (4%)	2 (4%)	**50 (100%)**		**28%**

Table 4.7 *Response counts for Group 3 (Teaching Experience ≥ 10 years) (N = 10)*
**Accurate response.*

When considering total responses for all steps, the most experienced teachers showed an overall tendency to focus most of their corrections on the pelvis (46%), followed by the thorax (32%) (Table 4.7). A more even distribution of responses was given within the two groups of less experienced teachers (Table 4.5 & Table 4.6). When combining all subjects, the thorax (29%) and pelvis (28%) were the two body regions most frequently selected for correction (Table 4.8).

Step (Accurate Response)	Answer Options							Total		% Accurate Responses
	Thorax	Pelvis	Hips	Knees	Ankles/ Feet	Other	None			
Grand Plié in First **(Thorax)**	**3***	9	2	5	10	0	4	33		9%
Rise Second **(Pelvis)**	12	**11***	2	1	2	2	3	33		33%
Grand Battement Derriere **(Ankles/Feet)**	15	6	2	3	**2***	3	2	33		6%
Double Pirouette En Dedans **(None)**	2	13	0	2	3	2	**11***	33		33%
Temps Levé **(Pelvis)**	16	**7***	1	5	3	0	1	33		21%
Total for All Steps	48 (29%)	46 (28%)	7 (4%)	16 (10%)	20 (12%)	7 (4%)	21 (13%)	**165 (100%)**		**21%**

Table 4.8 *Response counts for all participants (N = 33)* ********Accurate response.*

Reliability data (Table 4.9) indicate greater interrater reliability of responses between teachers with at least 10 years experience (k = 0.269), compared to teachers with less than 10 years experience (k = 0.070 - 0.075). Although higher than the less experienced groups, the reliability of accurate responses amongst the most experienced group was still very modest, with a reliability rating of only "fair" being achieved.

Group	0 Years Ballet Teaching Experience	1-9 Years Ballet Teaching Experience	≥10 Years Ballet Teaching Experience
Percentage Agreement (P_o)	0.203	0.207	0.373
Kappa (k)	0.070	0.075	0.269
Reliability Rating	Slight	Slight	Fair

Table 4.9 *Inter-rater reliability data for each group of teachers*

In relation to the accuracy of responses, comparison of the teacher's qualitative responses with quantitative data obtained from 3D motion capture reveals that there is only a very low level of response accuracy for all three groups of subjects. The highest mean percentage accuracy for any group is only 28%, this was achieved by the group of teachers with at least 10 years of professional experience (Figure 4.2).

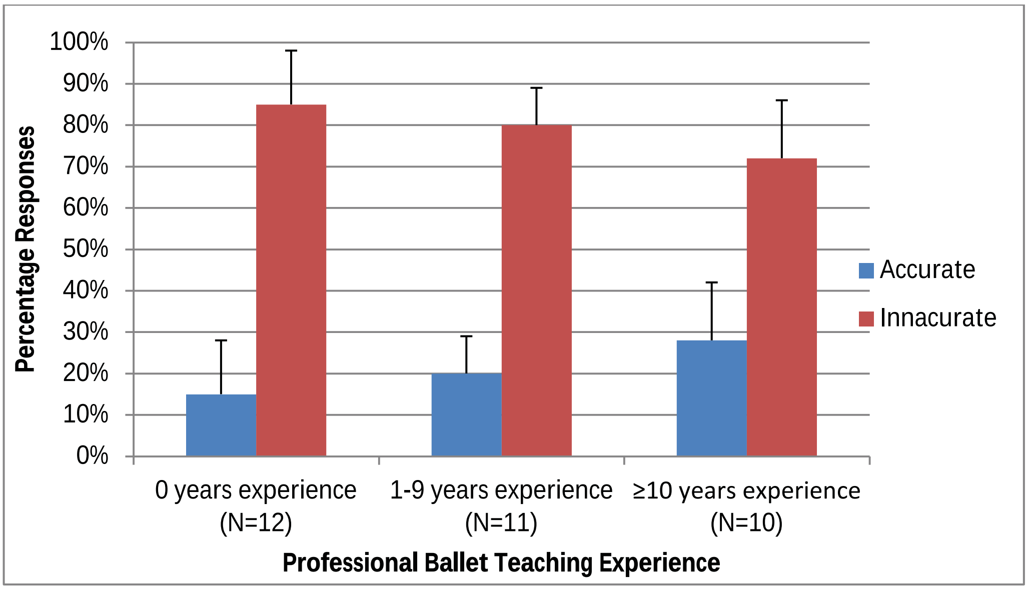


Figure 4.2 *Percentage accurate and inaccurate responses by group for identification of "which body region requires the most correction". Data include all responses for all steps. The range for "accurate" responses was 0-40% for all three groups. Error bars = +1 standard deviation.*

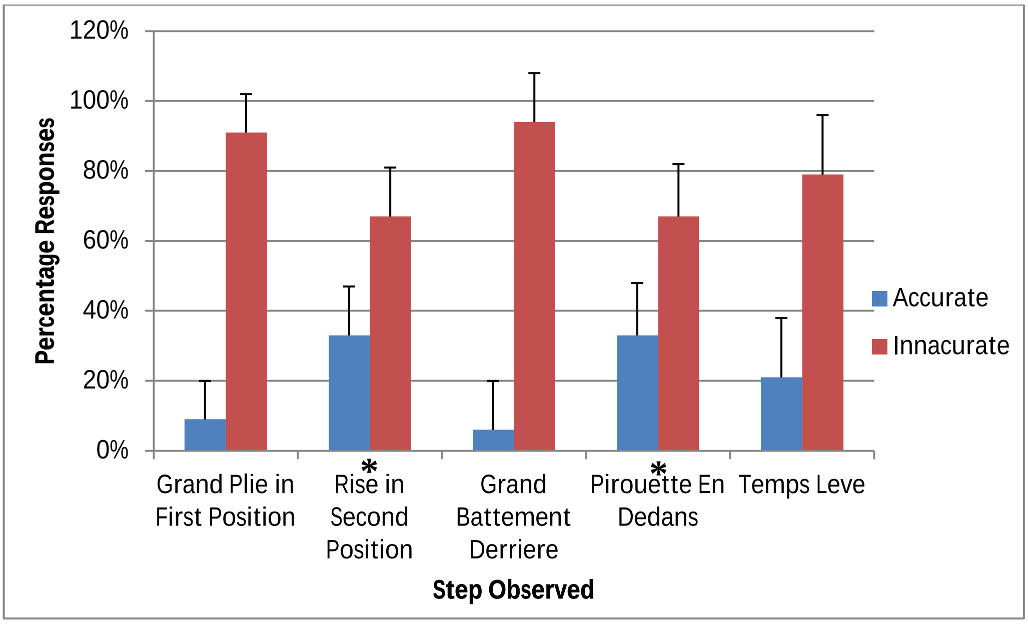


Figure 4.3 *Percentage accurate and inaccurate responses by step observed for identification of "which body region requires the most correction". Data include all responses for all subjects. (*******p < 0.05). Error bars = +1 standard deviation.*

Despite an apparent trend of increasing accuracy with increasing experience in classical ballet teaching (Figure 4.2), statistically, results of the binary logistic regression indicate that there is no significant main effect for "teaching experience" ($p = 0.147$) (Table 4.10). A significant main effect for "step observed" was demonstrated ($p = 0.028$), with greatest accuracy being obtained for the *rise* ($p = 0.037$) and *pirouette* ($p = 0.021$) steps.

		B	S.E.	df	Sig. (p)	Exp(B) Odds Ratio	95% C.I. for Exp(B)	
							Lower	Upper
Experience	0 years			2	0.147			
	1-9 years	0.519	0.525	1	0.323	1.681	0.6	4.705
	≥10 years	1.005	0.514	1	0.051	2.732	0.997	7.487
Step*	*Plié*			4	0.028			
	*Rise**	1.505	0.722	1	0.037	4.504	1.094	18.55
	Battement	-0.443	0.953	1	0.642	0.642	0.099	4.159
	*Pirouette**	1.65	0.717	1	0.021	5.207	1.276	21.246
	Temps Levé	1.011	0.747	1	0.176	2.747	0.635	11.884
Constant		-2.848	0.705	1	0	0.058		

Table 4.10 *Output (variables in the equation) for binary logistic regression of dependent variable "accuracy of identification of body region most in need of correction". Each category for each independent variable (Experience; Step) is compared to the reference category (i.e. first category listed). (*$p < 0.05$)*

4.3.3 Accuracy of Diagnosis of "Correct" or "Incorrect" Technique

Measures of accuracy for both "correct" and "incorrect' technique are presented in terms of an overall "percentage accuracy" score, calculated using responses to all 20 questions. "Percentage accuracy" data for each group are presented in Figure 4.4.

Because there was a non-uniform spread of "correct" and "incorrect" kinematic variables across each step and each body region, accuracy of qualitative analysis was not assessed in relation these parameters. That is, any apparent results indicating significant effects of step or body region could potentially be artefacts of whether or not correction was required. For this reason, the effects of step and body region on accuracy of qualitative analysis were not examined. The regression model therefore only contained one independent categorical variable: years teaching experience (0 years, 1-9 years,≥10 years). The binary dependent variable was "accuracy" with two possible options of "yes" or "no".

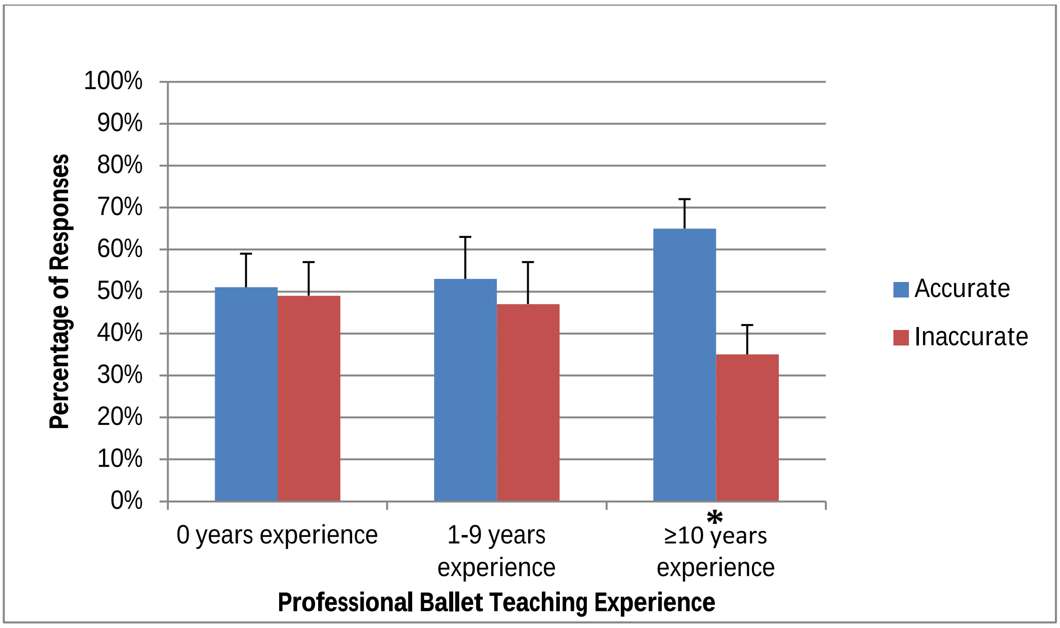


Figure 4.4 *Percentage accurate and inaccurate responses by group for identification of "correct and incorrect technique". Data include all responses for all steps. Error bars = +1 standard deviation.*

		B	S.E.	df	Sig. (p)	Exp(B) (Odds Ratio)	95% C.I. for Exp(B)	
							Lower	Upper
Experience*	0 years			2	0.013			
	1-9 years	0.077	0.187	1	0.679	1.081	0.749	1.559
	≥10 years*	0.547	0.196	1	0.005	1.728	1.176	2.539
Constant		0.05	0.129	1	0.699	1.051		

Table 4.11 *Output (variables in the equation) for binary logistic regression of dependent variable "accuracy of diagnosis of correct or incorrect technique". Each category for the independent variable (Experience) is compared to the reference category (i.e. first category listed). (*p < 0.05)*

Results of the regression model show that there is a significant main effect of "ballet teaching experience" on the accuracy of qualitative analysis of ballet technique ($p = 0.013$). Specifically, teachers with 10 or more years of teaching experience (Group 3) were more accurate in identifying correct or incorrect ballet technique ($p = 0.005$) than teachers with no experience (Group 1), or with 1 to 9 years experience (Group 2).

4.3.3.1 Further Investigation of the Effects of Teaching Experience on Accuracy of Diagnosis of "Correct" or "Incorrect" Technique

Having established, using categorical data, that there is a statistically significant main effect of "teaching experience" on the accuracy of diagnosis of "correct" or "incorrect" ballet technique, further analysis was conducted on the data from all subjects that had a minimum of one year of teaching experience. This analysis took the form of a linear regression of “years teaching experience” against “percentage accuracy”.

Overall, using data from all subjects with professional teaching experience (N = 21), results of the regression model again indicate that there is a significant effect of “years teaching experience” ($p = 0.023$) on the accuracy of identification of “correct” or “incorrect” ballet technique.

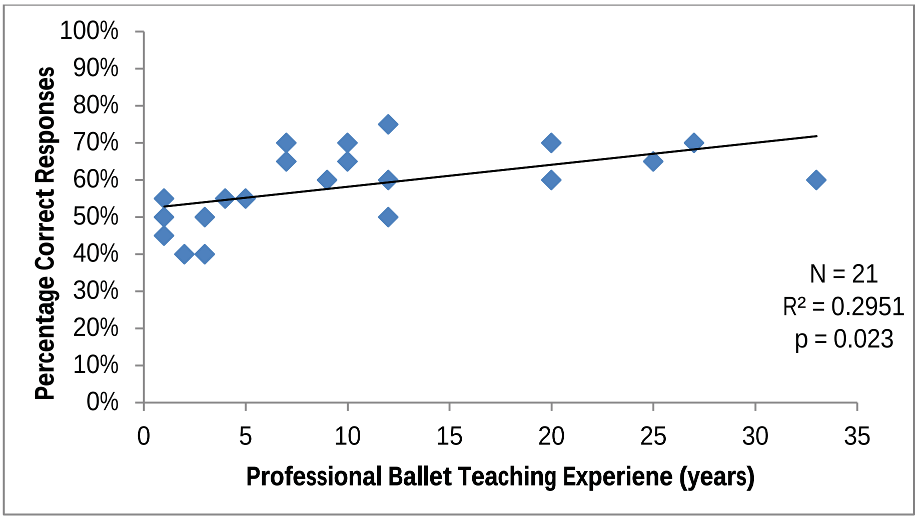


Figure 4.5 *Linear regression of “years teaching experience” against percentage accuracy for identification of “correct” or “incorrect” ballet technique.*

Separate linear regression analyses were also conducted on data for subjects with 1-9 years teaching experience (N = 11), and subjects with 10 or more years of teaching experience (N = 10). Again, regressions were conducted for “years teaching experience” against “percentage accuracy”. Results of the linear regression models show that there is a significant relationship, between “years teaching experience” and “percentage accuracy” for teachers with 1 to 9 years teaching experience ($p = 0.011$), but for 10 years of experience and above there is a no significant relationship between “years teaching experience” and “percentage accuracy” ($p = 0.961$). Figures 4.6 and 4.7 graphically display the results of these linear regressions.

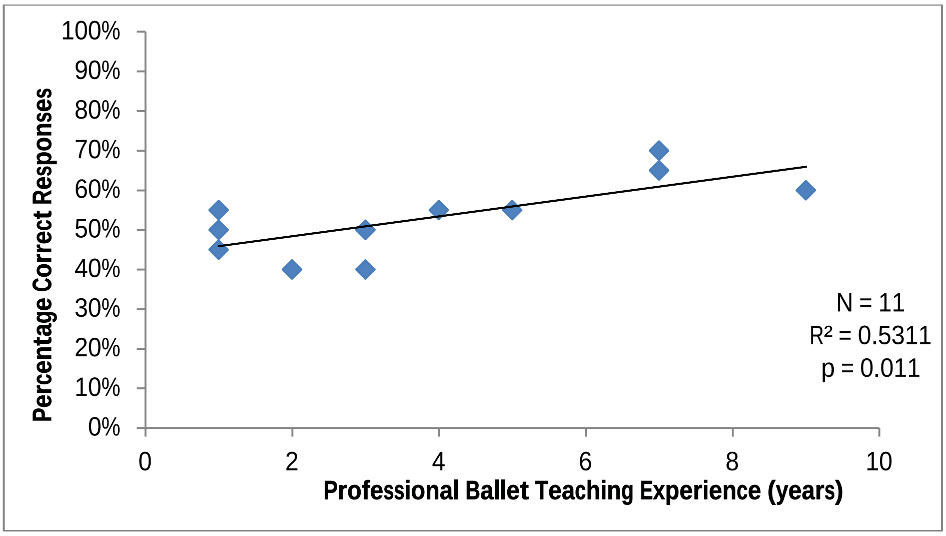


Figure 4.6 *Linear regression of "years teaching experience" against "percentage accuracy" for identification of "correct" or "incorrect" ballet technique for all teachers with 1-9 years experience*

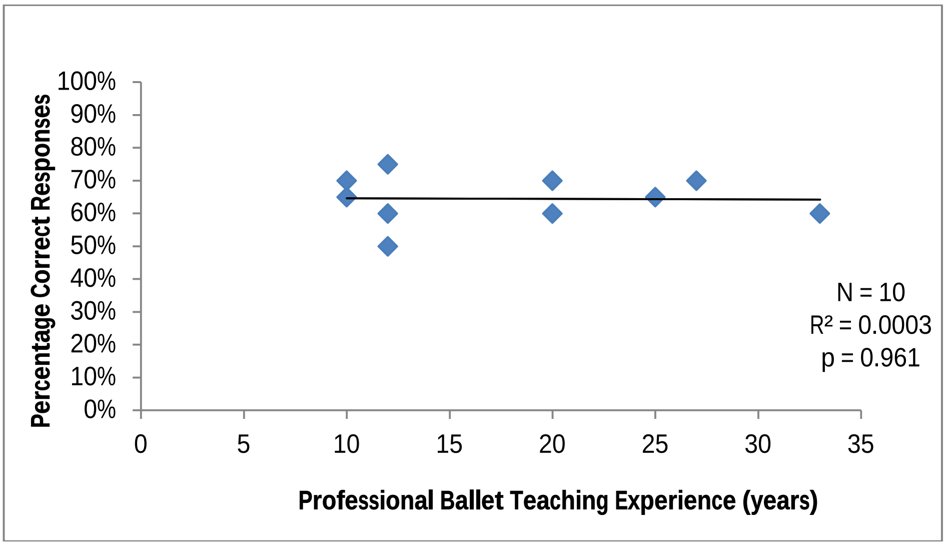


Figure 4.7 *Linear regression of "years teaching experience" against "percentage accuracy" for identification of "correct" or "incorrect" ballet technique for all teachers with 10 or more years experience.*

Having established that ballet teachers in the earlier period of their professional experience (*i.e.* 1-9 years) demonstrate improvement in accuracy with increasing experience, it is interesting to investigate how it is that their accuracy improves. That is, do they become more competent in accurately diagnosing correct technique or incorrect technique, or both? Separate linear regressions were therefore conducted to test for a relationship between accuracy of qualitative analysis of correct and/or incorrect ballet technique. Figures 4.8 and 4.9 depict the results of these analyses for teachers with 1-9 years experience.

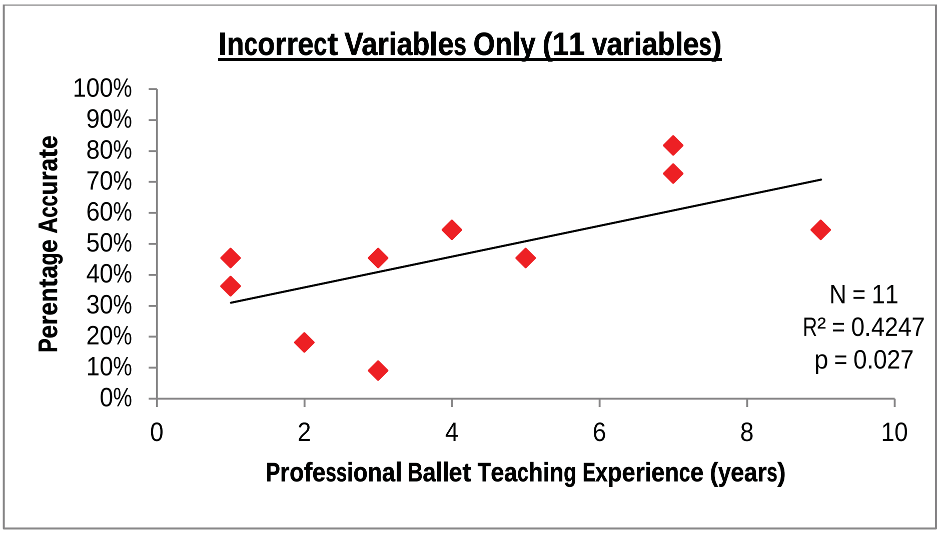


Figure 4.8 *Linear regression of "years teaching experience" against "percentage accuracy" for identification of "incorrect" ballet technique for all teachers with 1-9 years experience*

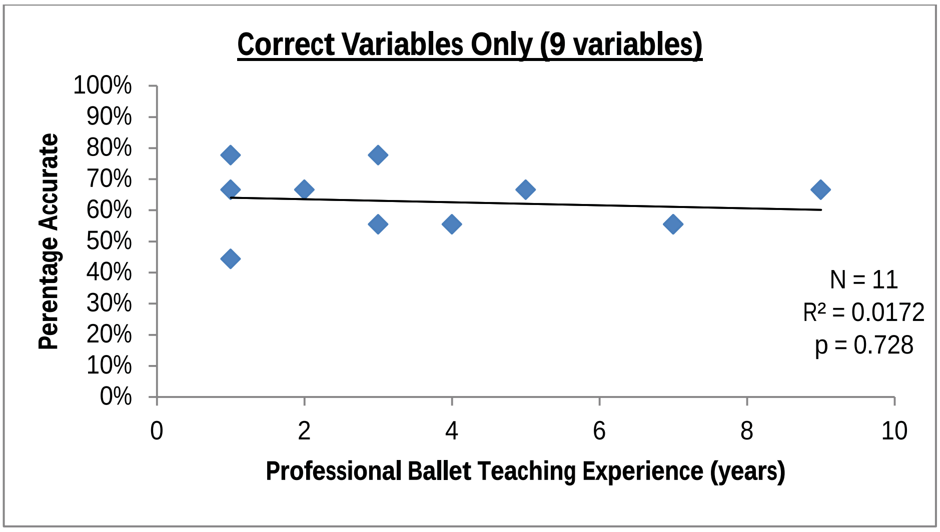


Figure 4.9 *Linear regression of "years teaching experience" against "percentage accuracy" for identification of "correct" ballet technique for all teachers with 1-9 years experience*

Results of the separate linear regressions of "percentage accuracy" of diagnosis of correct and incorrect technique, against years of teaching experience indicate that with increasing experience early career ballet teachers (1-9 years experience) become more competent at accurately identifying incorrect technique ($p = 0.027$), but do not significantly change in their ability to accurately identify correct technique ($p = 0.728$).

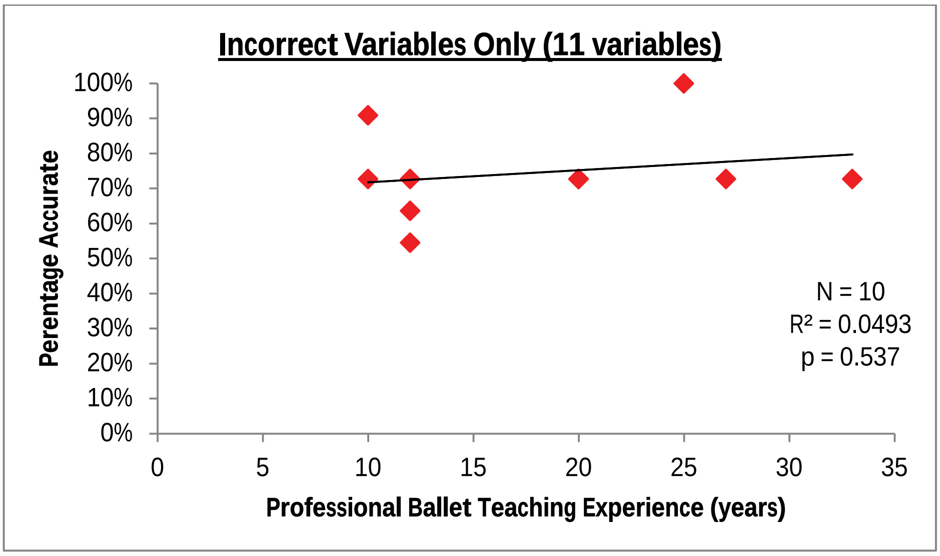


Figure 4.10 *Linear regression of "years teaching experience" against "percentage accuracy" for identification of "incorrect" ballet technique for all teachers with 10 or more years experience.*

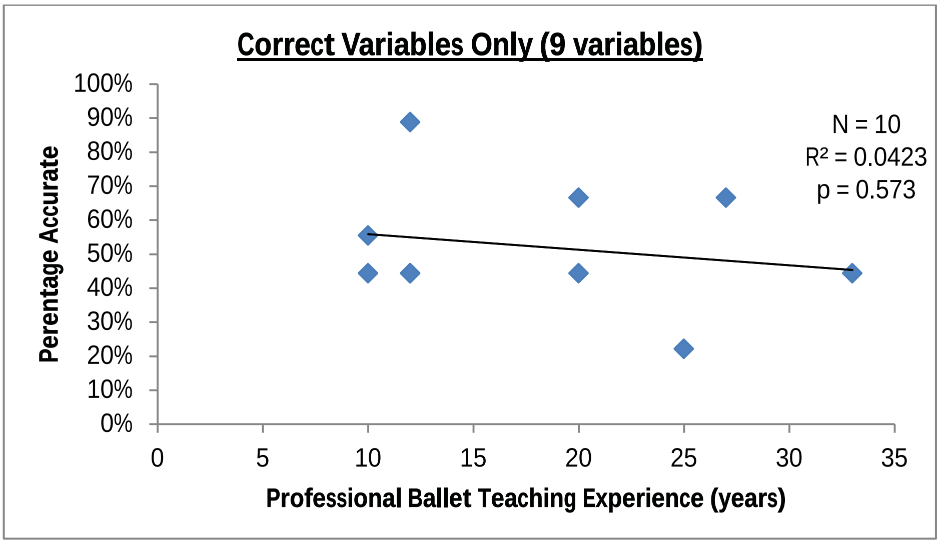


Figure 4.11 *Linear regression of "years teaching experience" against "percentage accuracy" for identification of "correct" ballet technique for all teachers with 10 or more years experience.*

A similar linear regression analysis was conducted on teachers with 10 or more years experience. These data reveal that for this group, the overall lack of increase in accuracy with increasing experience (Figure 4.7), was due to a lack of significant improvement in accurate diagnosis of either incorrect (Figure 4.10) or correct (Figure 4.11) ballet technique.

4.3.3.2 Effect of Teaching Experience on Type of Diagnostic Error

Despite achieving a statistically significantly higher "percentage accuracy" than all participants with less than 10 years teaching experience, the teachers with 10 or more years experience only obtained a mean "percentage accuracy" of 65%. Since a relatively large proportion of inaccurate response were returned by all groups, it is therefore interesting to investigate the types of errors made by each group. Figure 4.12 presents the proportions of Type I Errors (correct technique rated as "incorrect") and Type II Errors (incorrect technique rated as "correct") with respect to professional ballet teaching experience.

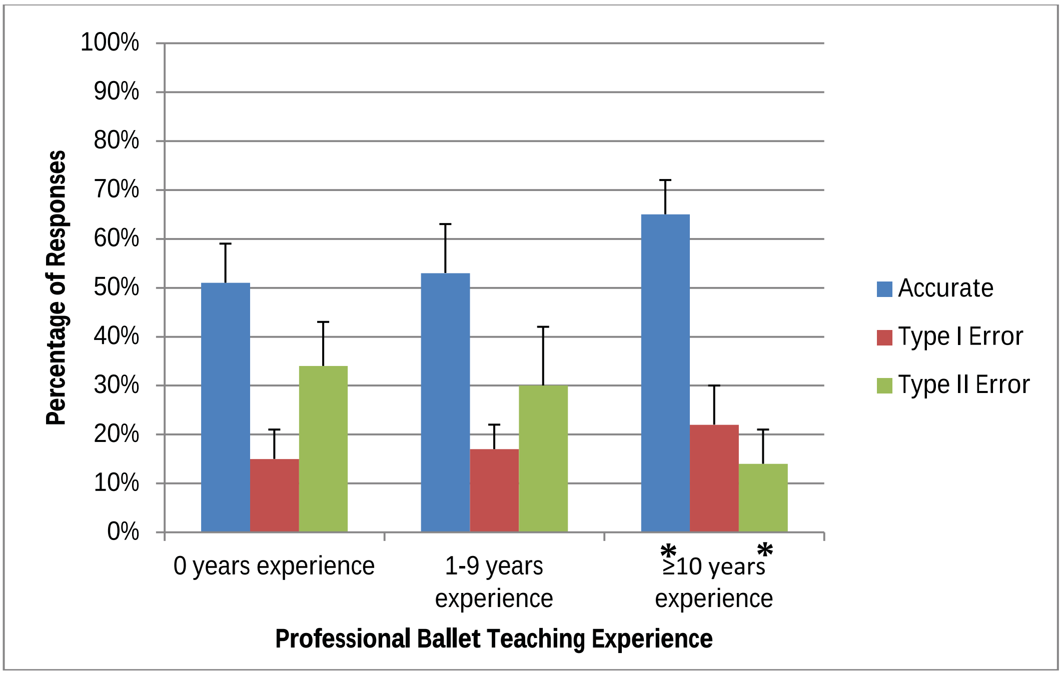


Figure 4.12 *Percentages of "Accurate" responses, and Type I and Type II Errors by group. (*p < 0.05). Error bars = +1 standard deviation.*

The student teachers with no professional ballet teaching experience achieved the lowest percentage (15%) of Type I Errors, in which they rated correct technique as "incorrect", and the highest percentage (34%) of Type II Errors, in which incorrect technique was rate as "correct" (Table 4.12). The proportions of error type were the opposite for the most experienced group of teachers. For the group with 10 or more years of experience, Type I Errors (21%) were more frequent than Type II Errors (14%).

Results of the binary logistic regression models show that there is not a significant main effect of "ballet teaching experience" on occurrence of Type I Errors (*i.e.* rating "correct" technique as "incorrect") (p = 0.109) (Table 4.12), but there is a significant main effect for Type II Errors (*i.e.* rating "incorrect" technique as "correct"), (p = 0.000). Specifically, teachers with at least 10 years experience obtained significantly fewer Type II errors than both groups of less experienced teachers (p = 0.000) (Table 4.13).

		B	S.E.	df	Sig. (*p*)	Exp(B) (Odds Ratio)	95% C.I. for Exp(B)	
							Lower	Upper
Experience	0 years			2	0.109			
	1-9 years	-0.177	0.291	1	0.544	0.838	0.473	1.483
	≥10 years	-0.604	0.294	1	0.040	0.547	0.307	0.972
Constant		0.693	0.204	1	0.001	2.00		

Table 4.12 *Output (variables in the equation) for binary logistic regression of dependent variable "occurrence of Type I Error". Each category for the independent variable (Experience) is compared to the reference category (i.e. first category listed).*

		B	S.E.	df	Sig. (*p*)	Exp(B) (Odds Ratio)	95% C.I. for Exp(B)	
							Lower	Upper
Experience*	0 years			2	0.000			
	1-9 years	0.280	0.256	1	0.273	1.324	0.802	2.184
	≥10 years *	1.537	0.283	1	0.000	4.651	2.673	8.093
Constant		-0.463	0.179	1	0.010	0.630		

Table 4.13 *Output (variables in the equation) for binary logistic regression of dependent variable "occurrence of Type II Error". Each category for the independent variable (Experience) is compared to the reference category (i.e. first category listed). (*p < 0.05)*

The significantly fewer occurrences of teachers with at least 10 years experience obtaining Type II Errors is consistent with the sensitivity data (Table 4.14). This group achieved the highest sensitivity value of 75%, indicating their increased ability to accurately identify "incorrect" technique. In contrast, this group achieved the lowest specificity (*i.e.* accurate identification of "correct technique"), this is consistent with their low percentage for Type I Errors.

Teaching Experience	Sensitivity	Specificity
0 years	39%	67%
1-9 years	45%	63%
≥ 10 years	75%	52%

Table 4.14 *Sensitivity and specificity by 'teaching experience'*

It is also interesting to assess the size of the deviations in joint angles that were considered, through quantitative means, to be "incorrect". That is, what size difference in joint angle results in "incorrect" technique for each joint, and how well can ballet teachers visually detect these differences? Table 4.15 provides a summary of the magnitude of the deviations in joint angles that were identified through quantitative means as being "incorrect". Data outlining the percentage of teachers in each category of teaching experience that were able to use visual observation to detect joint angle differences of these magnitudes are also presented in Table 4.15. These data show that mean differences of 5° in thoracic anterior/posterior tilt and 6° for pelvic anterior/posterior tilt were detected by 78% and 88% of experienced teachers (≥10 experience teachers), respectively. For knee flexion/extension, mean differences of 5° were less well detected by experienced dance teachers (60%), as were 7° differences in external hip rotation (40%). The high percentages of detection of deviations by experienced teachers indicate that for the thorax and pelvis, differences of 5° and 6° would constitute a "meaningful functional difference to the dance community". However for knee flexion/extension and external hip rotation, based on the qualitative analysis abilities of experienced ballet teachers participating in the current study, deviations of 5° and 7° may not constitute a "meaningful functional difference in the dance community".

	Thorax Ant/Post (°)	Pelvic Ant/Post (°)	Hip Int/Ext Rot (°)	Knee Flex/Ext (°)
Grand Plié First	4.6	4.6	0.3	1.4
Rise Second	3.0	5.8	7.4	5.3
Grand Battemant Derriere	8.3	9.1	2.9	6.5
Double Pirouette En Dedans	0.9	0.2	4.3	1.1
Temps Levé	5.5	5.4	2.5	4.6
Mean difference from professional dancer group mean	**5.3**	**6.2**	**7.4**	**5.9**
Teachers that detected error (All)	**61%**	**59%**	**24%**	**33%**
Teachers that detected error (≥10 years experience)	**78%**	**88%**	**40%**	**60%**
Teachers that detected error (1-9 years experience)	**59%**	**48%**	**18%**	**27%**
Teachers that detected error (0 years experience)	**48%**	**46%**	**17%**	**17%**

Table 4.15. *Average difference between individual dancer joint angle data and professional dancer group mean, and percentage of teachers that detected error. Variables for which z-value ≥1.*

4.3.3.3 <u>Effect of Professional Performance Experience and Teacher Training on Accuracy of Identification of "Correct" or "Incorrect" Technique</u>

Independent-samples t-test data for the group of professional teachers who were at least 24 years of age (N = 14), (*i.e.* those of an age at which they could have completed at least 6 years of professional performance experience as a classical ballet dancer), indicate that there is no statistically significant difference (p = 0.783) in accuracy of identification of "correct" and "incorrect" ballet technique between teachers who have and have not previously worked as a professional ballet dancer (Table 4.16).

Group	N	Mean "Percentage Accuracy"	Std. Dev. "Percentage Accuracy"	Std. Error Mean	95% CI		t-test p value
					Lower	Upper	
Not Former Professional Ballet Dancer	6	63.3%	6.1%	2.5%	-9.093	7.010	0.783
Former Professional Ballet Dancer	8	64.4%	7.8%	2.7%			

Table 4.16*. Results of independent-samples t-test for effects of professional performing experience on "percentage accuracy".*

An independent-samples t-test also shows that there is no statistically significant difference (p = 0.855) in accuracy of identification of "correct" and "incorrect" ballet technique between teachers who have and have not completed a teacher training program (Table 4.17).

Group	N	Mean "Percentage Accuracy"	Std. Dev. "Percentage Accuracy"	Std. Error Mean	95% CI		t-test p value
					Lower	Upper	
No Teacher Training	7	63.6%	5.6%	2.1%	-9.139	7.710	0.855
Teacher Training	7	64.3%	8.4%	3.2%			

Table 4.17 *Results of independent-samples t-test for effects of teacher training program on "percentage accuracy".*

4.3.4. Accuracy of Identification of "Type of Correction Required"

The mean number of variables rated as "incorrect" by each group, of the possible 11, were 3.9, 4.7, and 7.7 for participants with no professional ballet teaching experience, 1 – 9 years professional ballet teaching experience, and 10 or more years of professional ballet teaching experience, respectively. Results of a oneway ANOVA reveal that teachers with 10 or more years of experience identified significantly more kinematic variables as being “incorrect” compared to less experienced teachers (F = 13.8; p = 0.000).

Results of the binary logistic regression model (Table 4.18) show that there is no significant main effect of “ballet teaching experience” (p = 0.087) or step observed (p = 0.777) on the accuracy of identification of the type of correction required, but data indicate that there is a significant main effect for body region observed (p = 0.006). In particular, the corrections given for the knee (p = 0.027) and pelvis (p = 0.009) were more accurate than corrections given for the thorax.

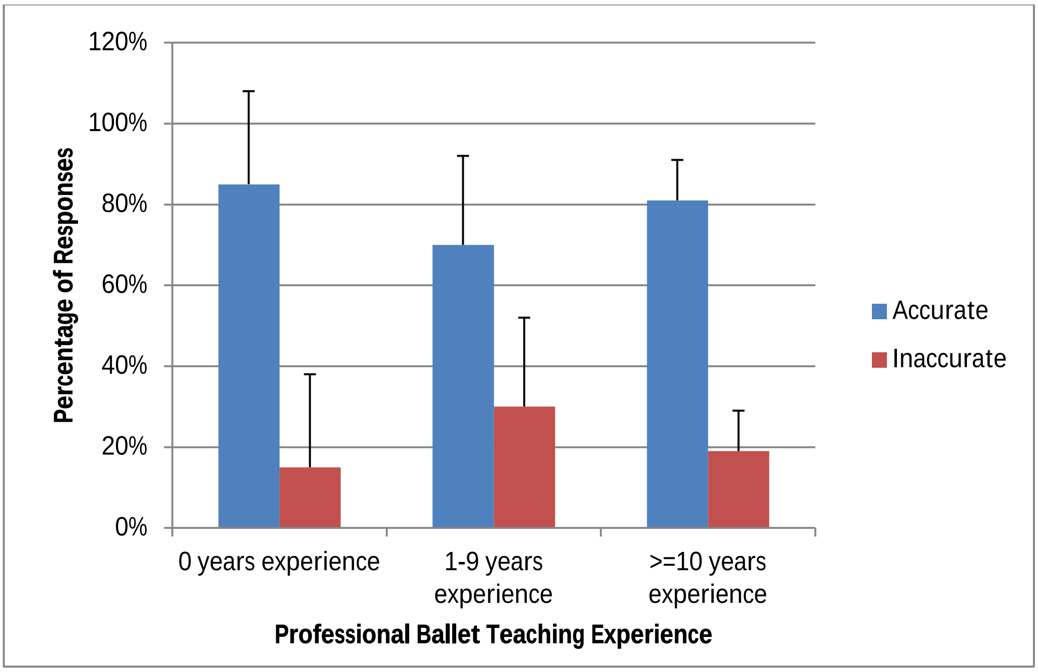


Figure 4.13 *Percentage accurate and inaccurate responses by group for identification of “type of correction required”. Data include all responses for all steps. Error bars = +1 standard deviation.*

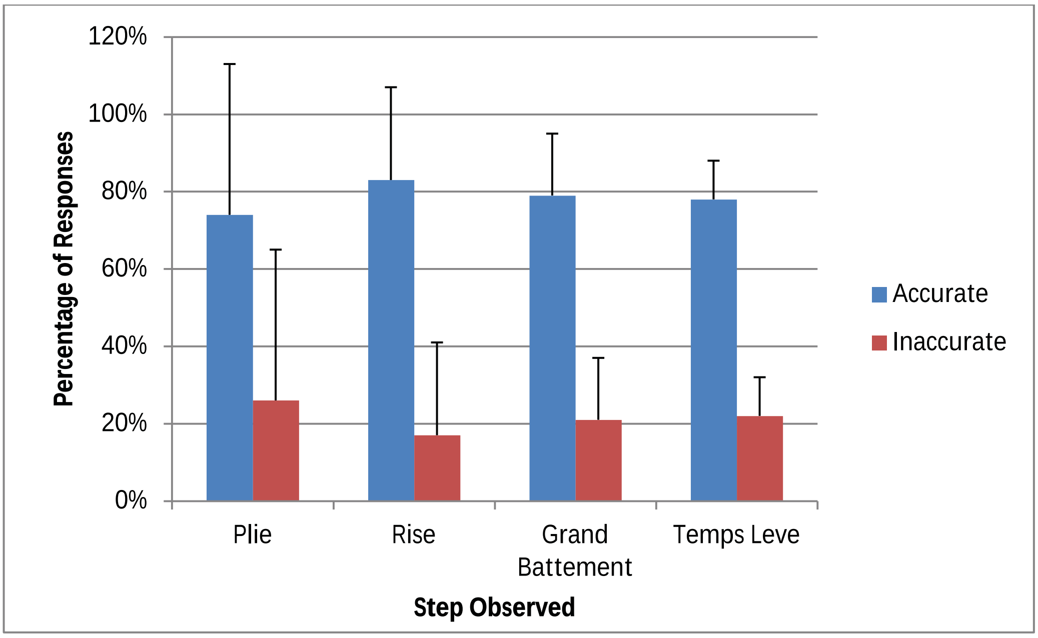


Figure 4.14 *Percentage accurate and inaccurate responses by step observed for identification of "type of correction required". Data include all responses for all subjects. Error bars = +1 standard deviation.*

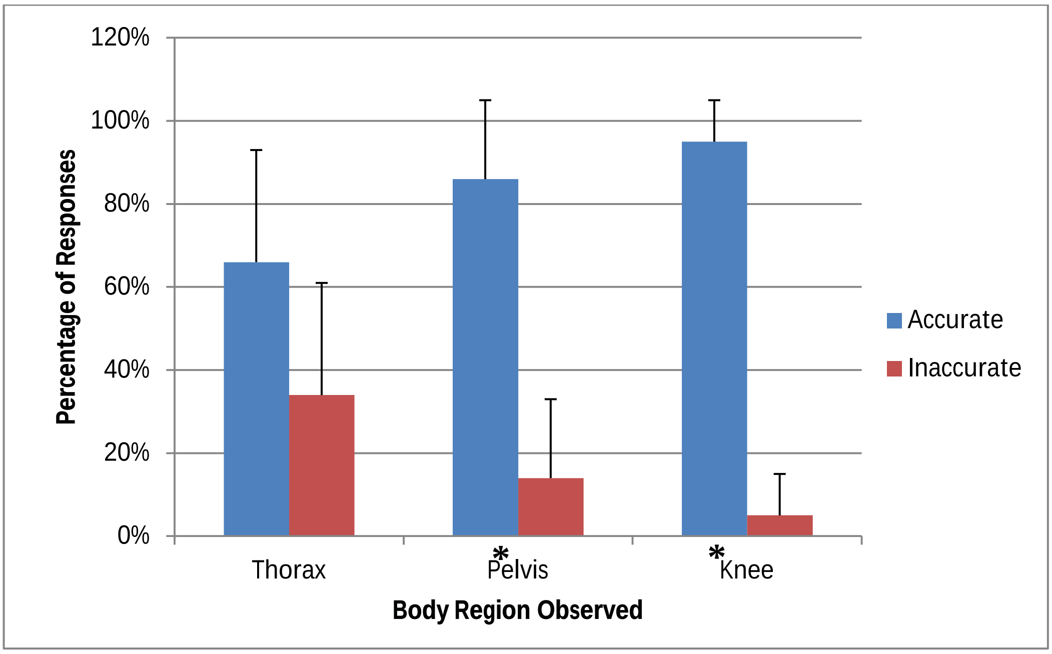


Figure 4.15 *Percentage accurate and inaccurate responses by body region observed for identification of "type of correction required". Data include all responses for all subjects. Error bars = +1 standard deviation.*

		B	S.E.	df	Sig. (p)	Exp(B) Odds Ratio	95% C.I.for Exp(B)	
							Lower	Upper
Experience	0 years			2	0.087			
	1-9 years	-1.196	0.549	1	0.029	0.302	0.103	0.887
	≥10 years	-0.646	0.54	1	0.231	0.524	0.182	1.509
Step	*Plié*			3	0.777			
	Rise	0.513	0.57	1	0.368	1.67	0.546	5.108
	Battement	0.205	0.558	1	0.713	1.227	0.411	3.663
	Temp Levé	0.475	0.561	1	0.398	1.607	0.535	4.831
Body Region*	Thorax			2	0.006			
	Pelvis*	1.107	0.423	1	0.009	3.027	1.321	6.937
	Knee*	2.387	1.081	1	0.027	10.886	1.309	90.552
Constant		1.089	0.588	1	0.064	2.971		

Table 4.18 *Output (variables in the equation) for binary logistic regression of dependent variable "accuracy of type of correction". Each category for each independent variable (Experience; Step; Body Region) is compared to the reference category (i.e. first category listed). (*******p < 0.05)*

4.4 Discussion

The accuracy with which professional and student classical ballet teachers identify "correct" and "incorrect" classical ballet technique was investigated by comparing their qualitative responses with 3D quantitative data. Data were analysed with respect to three groups of teaching experience: 0 years experience; 1-9 years experience; and $\geq$ 10 years experience.

4.4.1 Accuracy and Reliability of Identification of the "Body Region Most in Need of Correction"

In their first observation of each ballet step, participants were not given specific instructions as to which part of the body to observe, but were instead given the opportunity to use their own observation strategy. In watching each step the participants were asked "which body region, if any, would you concentrate on correcting". Very low percentage accuracy scores were achieved for all groups for this task (*i.e.* 15%, 20% and 28% for 0, 1-9 and $\geq$10 years experience, respectively), with no statistically significant difference between groups. Amongst studies that have investigated the accuracy of qualitative analysis through comparison with quantitative data (Section 2.3), no study was identified in which participants were able to choose where and what to observe. As far as the author is aware therefore, this is the first study of its kind in which participants were not directed to observe specific body regions, or look for particular movement qualities when asked to identify "correct" or "normal" movements. Consequently, it is not possible to compare the results for this style of question with existing published data.

The most experienced group of teachers achieved greater interrater reliability (*i.e.* "fair") than both less experienced groups (*i.e.* "poor"), indicating that when using their own observation strategy there is greater consistency amongst the more highly experienced teachers. Teachers with at least 10 years experience chose to correct the pelvis 48% of the time and the thorax 32% of the time, compared to 0-8% for all other regions. It was body regions or movements relating to the fundamental principles of 'placement' and 'alignment' therefore, which were most frequently identified as needing correction by the most experienced teachers. For both less experienced groups, there was a more even distribution of body regions selected for correction. It therefore appears that despite their low accuracy in terms of agreement with the quantitative data, as a group the most experienced teachers are more consistent and perhaps more systematic in their method of analyses. Results from studies on the visual search strategies used by movement coaches and judges have found that novices and experts differ in their search patterns. Visual search strategy refers to the "way that the eyes move around the display in an attempt to direct visual attention towards relevant sources of information" (Williams, 2002, p169). It has been reported that compared to novices, expert movement coaches and judges have fewer fixations and that these are of longer duration (Bard *et al.*, 1980; Moreno *et al.*, 2002; Avila and Moreno, 2003). Observer experience has also been found to influence the body regions which are most commonly fixated upon (Bard *et al.*, 1980; Petrakis, 1986). For example, expert gymnastic judges fixated on the upper body (*i.e.* head, arms), while the novice viewed the lower body (*i.e.* legs) (Bard *et al.*, 1980). It has generally been concluded therefore that experts have a "more compact scan path" (Petrakis, 1986, p258) and are more selective in their search strategy as they know which are the most informative areas of the display and ignore areas that do not provide important information. Moreover, it has been suggested that to effectively facilitate movement skill acquisition, instructors and coaches should have a "well-developed internal template or model of the kinematic characteristics of sound technique" (Sherman *et al.*, 2001, p258). It is possible therefore, that in the current study the increased frequency of selection of the pelvis and thorax by the more experienced teachers reflects prolonged fixation on these areas, due to these teachers' 'internal template' being based primarily on the movements of these regions. That is, perhaps for the experienced teachers, pedagogical experience has shaped the development of their 'internal template', thereby influencing the way in which they prioritise observation of and focus on particular body regions.

4.4.2 Accuracy of Diagnosis of "Correct" or "Incorrect" Technique

All groups of ballet teachers achieved better accuracy of qualitative analysis when directed to look at specific body regions, and answer either "yes" or "no" to whether the dancers needed correction in this area. Overall percentage accuracy scores were 51%, 53%, and 65% for this question for teachers with 0, 1-9 and $\geq$10 years experience, respectively, compared to 15%, 20% and 28% when allowed to choose their own area of observation. This improvement in accuracy of observation is consistent with the findings discussed in the literature review (Section 2.3), where it was concluded that the number of parameters observed, and the number of scale categories or answer options affects accuracy of observation. In the first style of question, teachers were essentially required to observe the dancer’s whole body and select from one of seven possible categories. In subsequent questions however, teachers were directed to observe only one specific body region, were told exactly which movement variable to assess, and were only provided with two answer categories. The improvement in accuracy obtained for this type of question is therefore consistent with existing literature in regards to the factors that affect accuracy of qualitative analysis of human movement. However, despite this improvement, it should be noted that with only two options to select from, the increased scores were still only slightly better than chance (*i.e.* 50%), particularly for the less experienced groups.

In considering the effect of teacher experience on accuracy of identification of “correct” and “incorrect” classical ballet technique, teachers with at least 10 years experience performed significantly better than both groups of teachers with less than 10 years experience. A similar effect of teaching experience on accuracy of observation of skilled movement was reported by Imwold and Hoffman (1983) and Plessnier and Schallies (2005) for analysis of gymnastics, however, Knudson (1999) found that teaching experience did not significantly affect accuracy of observation for general physical education activities such as the vertical jump. It has been reported (Biscan and Hoffman, 1976) that familiarity with and exposure to particular movements increases the ability to compare these movements to an ideal movement prototype or template. Instruction of activities such as gymnastics or classical ballet requires knowledge and familiarity with very specific and precise movement styles, more so than general physical education activities. The increased accuracy of observation demonstrated by the more experienced group, may therefore reflect increased familiarity enabling more accurate comparison of the observed movements with the ideal prototype.

In the current study, significant improvements in accuracy of qualitative analysis occurred between 1 and 9 years experience, however this improvement plateaued beyond 10 years experience. It is therefore the earlier rather than later phases of a dance teaching career when significant improvement in qualitative analysis is made. Chase and Simon

(1973) proposed that the attainment of expertise in any skilled activity was the result of acquiring vast amounts of knowledge and ability during many years of experience in a particular domain. Specifically, it has been stated (Chase and Simon, 1973; Bloom, 1985) that a 10 year rule of necessary preparation can be generalised to several different domains. According to this rule, "not even the most 'talented' of individuals can attain elite performance without approximately 10 years of preparation" (Chase and Simon 1973, p240). Perhaps it is this "rule" that is responsible for the better accuracy demonstrated in the current study by teachers with at least 10 years experience, however it does not necessarily explain the plateau in accuracy for these teachers beyond the 10 year mark.

Ericsson and Charness (1994, p783) state that "individuals improve their performance and attain an expert level, not as an automatic consequence of more experience with an activity but rather through structured learning and effortful adaptation". Perhaps in the earlier phase of their professional teaching career (1-9 years) ballet teachers put more effort and interest into improving their skills, and that after 10 years of experience this effort declines Thus, simply continuing to instruct ballet without concerted effort being placed on improving specific components of teaching practice, may not necessarily result in improved skill with continued experience. According to Ericsson *et al.* (1993), the primary mechanism responsible for creating expert performance in a domain is deliberate practice, during which optimal opportunities for learning and skill acquisition are provided. Most people spend a very small amount of time on deliberate efforts to improve their performance once it has reached an acceptable level. Under these conditions only weak relations between experience and performance would be predicted (Ericsson *et al.*, 1993; Ericsson and Charness, 1994). So, according to this suggestion, it may be that after 10 years of experience, classical ballet teachers feel satisfied with their level of competence and therefore less deliberate effort is directed towards skill improvement.

Despite the improvement in accuracy when teachers were required to observe only one body region, and the significantly greater accuracy achieved by the most experienced group, in effect the percentage accuracy scores are actually surprisingly low. An average result of 65% accuracy for the teachers with at least 10 years experience is modest, and indicates that these experienced teachers were inaccurate in rating ballet technique as either "correct" or "incorrect" for over one third of observations, and only 15% better than through pure chance. Other studies that have reported "percentage accuracy" of qualitative analysis, based on comparison of responses with quantitative kinematic data, have presented higher accuracy results. For qualitative gait analysis Patla and Clouse (1988) obtained percentage accuracy data ranging from 40% to 84% and Wren *et al.* (2005) reported values of 61% to 88%. In comparison to the highest percentage accuracy values obtained for these clinical qualitative observations, the data obtained in the current study are low. Given that some of the teachers in this group had as much as 20 and 30 years teaching experience, this level of inaccuracy does not engender confidence in the qualitative analysis and diagnostic abilities of highly experienced professional ballet teachers.

A possible explanation for the relatively low accuracy of qualitative analysis achieved even for experienced teachers may be that most of the dancers appearing in the videos only deviated slightly from the "ideal" or correct position. The dancers used in the videos were all of a professional level, and while they deviated from the group mean by more than one standard deviation for nearly half of the variables observed, they were still highly skilled dancers. Research (Wren *et al.*, 2005; Plessner and Schallies, 2005; Passier *et al.*, 2010; Dallas *et al.*, 2011) has shown that the degree of deviation from an ideal or easily identifiable angle (*e.g.* neutral) influences the level of accuracy of observation. For example, accuracy of visual observation of joint position increases with increasing deviation of a joint angle from neutral. This suggests that if less experienced dancers with greater deviations from the ideal appeared in the videos, the teachers would have achieved better percentage accuracy scores. The results indicate that at the more highly skilled and elite end of movement instruction (*i.e.* instruction of those that have already achieved an elite level), the naked eye is not well enough equipped to detect subtle differences and problems in technique. At a high level of movement ability corrections become more refined and subtle, consequently the ability to accurately diagnose technique at this level is extremely important.

Although only achieving modest accuracy even after 10 years experience, it was the identification of "incorrect" technique that is primarily responsible for the overall improvement demonstrated during the 1 to 9 year phase of experience. Student teachers with no professional experience performed poorly in identifying "incorrect" technique and therefore obtained the highest proportion of Type II Errors, while teachers with at least 10 years experience obtained significantly fewer errors of this kind. That is, with increasing experience from 0 years to over 10 years experience, the teachers' "sensitivity" to the detection of "incorrect" technique increased from 39% to 75%. However, in relation to accurate identification of "correct" technique (*i.e.* "specificity"), a similar trend of increased accuracy was not observed. In fact, although not to a significant degree, "specificity" declined slightly with experience, indicating that more experienced teachers are more "picky", and thus have a higher threshold for identification of technique as being "correct".

Interestingly, the findings obtained in relation to observer experience and error type are contradictory to some existing literature. Armstrong and Hoffman (1979, p326) stated that "novice teachers create more false alarms, *i.e.* they reported the presence of an error when the error was not demonstrated more often than experienced teachers". It was concluded that experienced teachers are therefore less willing than inexperienced teachers to take the chance of making a diagnostic error in identifying technique as "incorrect". Similarly, Knudson (2000, p19) stated that "many novice instructors are on a mission to identify errors and tend to over emphasise corrective feedback". This tendency was defined as a "corrective complex". However, the results of the current study do not concur with the suggestions of either of these authors. In fact, the current study found an opposite tendency, in that compared to the less experienced teachers, the more experienced teachers (*i.e.* ≥10 years professional teaching experience) showed a greater tendency to rate correct elements as "incorrect".

Gordon (1970, p369) reported that the actual correctness of behaviour observed is a major factor in determining the accuracy of ratings, and developed the term "Differential Accuracy Phenomena" (DAP). This term was defined as "the numerical difference in raters' ability to identify correct and incorrect forms of behaviour or movement". Gordon (1970) and Osborne and Gordon (1972) both reported that ratings were more accurate when the behaviour or movement was actually "correct" rather than "incorrect", a finding that would result in a positive DAP. Such a result is consistent with the data obtained for the less experienced teachers (*i.e.* 0 years and 1-9 years experience) who demonstrated higher specificity than sensitivity, but not for teachers with at least 10 years experience. The most experienced group obtained greater sensitivity (75%) than specificity (52%) indicating that they were more accurate in identifying “incorrect” technique. Ste-Marie (1999) obtained data consistent with this finding for experienced gymnastics judges in that expert judges were found to be more accurate in identifying form errors in performance than novice judges.

Amongst the professional teachers, there was no significant effect of having had a professional performance career on accuracy of identification of “correct” and “incorrect” ballet technique. However, previous authors (Locke, 1972, p380) have observed that among physical education teachers, the “one with the analytical advantage seems more often than not to be the one who has performed, practised and studied specific components of the skill”. Similarly, Sherman (2001, p259) reported that “a close functional relationship exists between level of physical performance and the ability to observe and interpret movement patterns”. Osborne and Gordon (1972, p55) however, stated that accuracy of ratings was not linked with the physical skill level of the rater. The current data are in agreement with Osborne and Gordon (1972), in that it was experience in ballet instruction rather than ballet performance that influenced accuracy of qualitative analysis of classical ballet. Also of note is the finding that participation in a teacher training program had no effect on accuracy of qualitative analysis amongst professional ballet teachers. Perhaps this indicates that curricula including specific training on methods for qualitative analysis of dance technique have been lacking in teacher training programs to date.

4.4.3. Accuracy of Identification of “Type of Correction Required”

If teachers did identify that correction was required for a particular step, they were asked to specify what type of correction was most appropriate. They were given two possible correction options to choose from. Overall, percentage accuracy results for responses to this question were 85%, 70% and 81% for 0, 1-9 and $\geq$10 years experience, respectively. Thus, qualitative analysis of the type of correction required was more accurate than identification of whether or not a correction was required. It is interesting that neither teaching experience nor the step observed significantly influenced the accuracy of identification of the type of correction required, however there was a significant effect of body region observed. In particular, the corrections given for the knee and pelvis were more accurate than those given for the thorax. Perhaps there is more agreement among ballet teachers as to what constitutes "correct" technique for pelvic 'placement' and knee 'extension', than for thoracic 'alignment'. Alternatively, since review of the literature on accuracy of qualitative analysis of human movement (Section 2.3) indicates that the body region observed influences accuracy of observation, it could be that when assessing classical ballet technique, observation of the pelvis and knee is typically more accurate than for the thorax.

4.4.4 Limitations

The main limitation associated with this study is the number of professional dancers from which "gold standard" kinematic data were obtained. Data averaged from 12 professional dancers were used as a reference for determination of "correct" classical ballet technique. Inclusion of data from more professional ballet dancers would certainly add validity to the method by which "correct" and incorrect" technique were identified. A specific aim for additional research of this kind would therefore be to increase the sample size on which the "gold standard" kinematic data are based.

It is possible that the very low accuracy results obtained for the question on "which body region, if any, would you correct", are due to the fact that the quantitative method by which the most "incorrect" body region was identified was not based on anatomical or pedagogical theory or knowledge. Instead it was based purely on the highest numerical measure of deviation, with no judgement or prioritisation of the importance of each body region in achieving correct classical ballet technique. In selecting their answers however, the participating teachers were likely to have used some level of logic or reason, based on their understanding of classical ballet technique. Perhaps therefore, this style of question and analysis was not a valid means of measuring accuracy of qualitative analysis, but instead exposes the teachers' judgments on the prioritisation of corrections.

So as not to influence their qualitative responses, participants were not informed of the proportions of dance videos that contained "correct" and "incorrect" technique. Given that they were taking part in a scientific experiment, it is possible that the teachers could have assumed that there were in fact errors in technique in most of the videos they observed. Therefore despite efforts to eliminate potential bias, it is possible that the circumstance itself could have introduced bias into the participants' responses. However, the finding that there was a significant difference between groups in the number of variables identified as "incorrect", indicates that it is likely that the experimental condition was not a significant limitation.

Given that academic literature to date has not provided conclusive evidence on the effect of the mode of observation (*i.e.* live vs. video) on the accuracy of qualitative analysis of human movement (Section 2.3), it is difficult to know whether the use of video analysis in the current study can be perceived as a limitation. It is acknowledged that dance teachers typically perform live rather than video observations of their students, and are able to move around the dance studio to achieve what they consider to be the best vantage point. Therefore, in an effort to reproduce this situation as closely as possible, and in accordance with the finding that camera or viewing angle does affect accuracy of observation (Section 2.3), a synchronised dual-perspective view was provided for each video in order to minimise any limitations introduced by the methods used.

4.4.5 Conclusions

The conclusion emerging from this study is that experience in classical ballet instruction has a significant effect on accuracy of qualitative analysis of classical ballet technique. Participation in a teacher training program or attainment of a professional classical ballet performance career however, does not significantly influence the accuracy of assessment of classical ballet technique.

When asked to focus on one body region only, teachers with at least 10 years experience demonstrated significantly better accuracy of identification of "correct" and "incorrect" ballet technique than teachers with less than 10 years experience. Amongst the teachers in the earlier phase of their teaching careers (*i.e.* 1-9 years experience), a significant relationship was identified between years experience and accuracy of qualitative analysis, however this was not the case beyond 10 years of experience. Instead, a plateau effect was observed, where accuracy of observation did not continue to increase with increasing experience beyond 10 years. The increase in accuracy of qualitative analysis during the 1-9 year phase of experience occurred as a result of increasing "sensitivity" to the detection of “incorrect” technique. However, a similar trend was not observed for identification of “correct” technique (*i.e.* “specificity”).

Despite improvements in accuracy during the first 10 years of teaching experience, overall, the most experienced group of teachers only achieved an average percentage accuracy score of 65%. This modest result indicates that when observing highly skilled dancers, the qualitative analysis abilities of classical ballet teachers may be ineffective, and suggests that increased training in this skill is warranted. Given the relatively low percentage accuracy scores achieved, it is proposed that development and use of a quantitative assessment tool, based on 3D motion analysis, could provide a more objective and systematic process for evaluation of classical ballet technique. The following chapter will describe the analyses conducted during development of such a tool, and will present examples of the information the tool could potentially provide.

CHAPTER 5

DEVELOPMENT OF A QUANTITATIVE TOOL FOR ASSESSMENT OF CLASSICAL BALLET TECHNIQUE

CHAPTER 5
DEVELOPMENT OF A QUANTITATIVE TOOL FOR ASSESSMENT OF CLASSICAL BALLET TECHNIQUE

5.1 Introduction

The use of instrumented quantitative techniques to analysis dance movements has been steadily increasing over the last few decades. Of particular note is the growing use of 3D motion analysis techniques in dance science research during the past five to seven years (Section 2.2.2). Dance science researchers have used 3D motion analysis to measure and describe the movements of various dance genres. The aims of this research have included: assessing how certain movements may be associated with injury; assessing how different types of floors or shoes may influence movement patterns; analysing how different training programmes may affect performance; investigating aspects of motor control; and to gain further insight into the general kinematics and kinetics of specific dance movements. Despite this increasing use of 3D analysis, it appears that the technology is not yet being used as a tool to routinely assess or screen individual dancers on basic aspects of their technical competency. To date, assessment and evaluation of competency in the fundamental principles of ballet technique occurs primarily through qualitative analysis, undertaken by dance instructors in the classroom or dance studio. This being the case, it is therefore crucial that dance teachers possess the necessary skills to conduct accurate and effective qualitative analysis.

The preceding chapter investigated the ability of both experienced and inexperienced ballet teachers to observe the performance of basic classical ballet steps and to detect correct or incorrect technique. That is, the degree of accuracy of the teachers' qualitative analysis skills were assessed. Comparison of the qualitative responses provided by the teachers with quantitative kinematic data obtained from 3D motion analysis, revealed that even ballet teachers with at least 10 years professional experience only achieved a mean overall percentage accuracy score of 65%. This result indicates that for up to one third of observations, experienced teachers were inaccurate in rating ballet technique as either "correct" or "incorrect", and this is only 15% above a result that could be obtained through chance alone. It could therefore be argued that a quantitative assessment tool in which student dancers' joint movement patterns are objectively compared to a "gold standard" of technique, as demonstrated by professional ballet dancers, could be very useful in providing a systematic method for the diagnosis of technical competency in classical ballet.

Despite the value of the increased biomechanical detail that can be obtained from full-body 3D motion analysis, it can be a laborious and time consuming process for all involved. In order to obtain accurate and meaningful biomechanical data, subject anthropometric data must be carefully measured, and reflective markers must be meticulously placed on specific anatomical bony landmarks. Motion analysis cameras must be accurately calibrated, and appropriate biomechanical models must be identified and correctly used. As is the case for 3D clinical gait analysis, currently routinely used in many hospitals throughout the world, 3D dance analysis could potentially take up to 2 hours to be conducted correctly. If a 3D quantitative tool was to be devised for analysis of classical ballet technique, in order for it to be a feasible routine practice, the process would need to be as efficient and cost effective as possible. The aim of this section of the research project then is to develop such a 3D quantitative tool consisting of a minimum number of independent quantitative kinematic variables and a minimum number of independent ballet steps for analysis. To do this, the kinematic data collected from a group of professional ballet dancers will be used as the "gold standard" for the practical execution of correct classical ballet technique. That is, a practical biomechanical benchmark of "correct" technique will be used, rather than theoretical principles. Kinematic data from individual non-professional dancers will be used as pilot data to assist with development of the assessment tool. The quantitative assessment tool will include the minimum number of kinematic variables that adequately represent the principles of 'alignment', 'placement', 'turnout', and 'extension'. Careful consideration will be given to the number and type of steps chosen for inclusion in the tool, with the aim of selecting a minimum number of steps that can effectively detect deviations in the relevant kinematic variables.

5.2 Methods

The kinematic data used for analysis in this section were obtained during the data collection sessions described in Chapter 3. The procedures for ethics approval, participant recruitment and consent, anthropometric measurement procedures, instrumentation, experimental protocol, and data processing were therefore the same as described in Section 3.2.

5.2.1 Data Extraction

Kinematic data collected from the group of professional dancers were used as a "gold standard", against which data from individual non-professional dancers were compared. It was therefore necessary to average the data across all professional dancers. To do this, time-normalised (0 to 100% of the movement) data sets were generated for each step for each dancer according to the step-specific 'start' and 'end' criteria described in Chapter 3 (Section 3.2.5). All data between the step 'start' and 'end' were divided into 20 evenly spaced time points (*i.e.* 5% intervals), and these were then averaged across the group of professional dancers. Time-normalised standard deviation data were also calculated for the professional group. This process was conducted for each of the nine kinematic variables that were identified in Chapters 2 and 3 as being the minimum number of variables that thoroughly represent the four fundamental principles of classical ballet technique.

Having obtained time-normalised group mean data for the professional dancers, individual data for each non-professional dancer were compared to the group data by calculation of z-scores. The z-score is a standard score expressed in terms of standard deviation units on a normal curve (Hastad and Lacy, 1994). This value indicates how far above or below a group mean an individual raw score is located. The z-score for an individual value is calculated using the group mean and standard deviation, according to the following formula:

$$z = \frac{\overline{x}-x}{s}$$

where $\overline{\chi}$ = group mean, χ = raw score , and s = standard deviation.

5.2.2 Consideration of Steps for Inclusion in the Quantitative Assessment Tool

In designing a quantitative assessment tool for classical ballet technique, it was very important to carefully consider which steps would be most appropriate for inclusion. Practically, the number of steps needed to be kept to a minimum, yet the steps needed to be effective in detecting deviations in the kinematic parameters that relate to the four fundamental principles of classical ballet technique. Thus, the process of step selection required identification of steps that were best able to detect differences between the professional and non-professional dancers in the following kinetic variables.

- Thoracic anterior/posterior tilt
- Thoracic side tilt
- Pelvic anterior/posterior tilt
- Pelvic obliquity
- Pelvic-thoracic transverse rotation
- Hip rotation
- Ankle rotation
- Knee extension
- Ankle plantarflexion

To identify which steps could best detect deviations in these parameters, a number of calculations based on z-scores were performed. Firstly, the z-scores at each of the 20 time-normalised data points that comprised a complete step were calculated. Then a single value representing the average z-score across all 20 time points was determined. This was done for each of the 9 kinematic variables, for each of the 14 steps, for all 14 non-professional dancers (Figure 5.1 – Phase 1). From there, the average z-score across all 14 dancers was calculated for each kinematic variable, and then an average z-score per step was calculated across all kinematic variables (Figure 5.1 – Phase 2). Because the magnitude, rather than the direction of the z-scores was of most interest (*i.e.* the amount of deviation of the non-professional data from the professional data, not the direction of deviation), the absolute values of the z-scores were calculated. The resultant overall z-score obtained for each step thus provided an indication of how well each step was able to detect deviations between the professional dancers and non-professional dancers across all nine kinematic variables throughout all time points within a single step cycle (Figure 5.1 – Phase 3).

Phase 1

***Plié in First Position* - Thorax Anterior/Posterior Tilt**

Time point	Dancer NP001	Dancer NP002	↔	Dancer NP014	Dancer NP015
0%	z-score	z-score		z-score	z-score
↕					
100%	z-score	z-score		z-score	z-score
	Mean z-score for thorax ant/post tilt for *plié in first*	Mean z-score for thorax ant/post tilt for *plié in first*		Mean z-score for thorax ant/post tilt for *plié in first*	Mean z-score for thorax ant/post tilt for *plié in first*

A: *Phase 1 conducted for all 9 kinematic variables for all 14 steps for all dancers

Phase 2

***Plié in First Position*

Kinematic Variables	Dancer NP001	Dancer NP002	↔	Dancer NP014	Dancer NP015	Mean z-score across all dancers
Thorax Ant/Post Tilt						
Thorax Side Tilt						
Pelvic Ant/Post Tilt						
Pelvic Obliquity						
Pelvic Ant/Post Tilt						
Hip Rotation						
Knee Flexion/Extension						
Ankle Plant/Dorsi Flexion						
Ankle Rotation						
						Overall mean z-score for step

C: Overall mean z-score taken across all kinematic variables

B: Mean z-score taken across all dancers for each kinematic variable for *plié in first position*

Phase 3

Movement Category	Step	Overall mean z-score for step
Bend (*Plié*)	*Plié in First Position*	
	Plié in Second Position	
Stretch (Battement)	*Battement Tendu Derriere*	
	Battement Jeté to 45° Front	
Rise (*Relevé*)	*Rise in First Position*	
	Rise in Second Position	
Jump (*Sauté*)	*Sauté s in First Position*	
	Temps Levé s	
Glide (*Glissade*)	*Glissades Over*	
	Glissades Under	
Dart (*Elancé*)	*Jeté Ordinaire*	
	Grande Jeté Elancé En Avants	
Turn (*Tour*)	*Pirouette En Dedans*	
	Pirouette En Dehors	

D: **Phase 2 conducted for all 14 steps

Figure 5.1 *Flow chart depicting process for calculation of overall mean z-score per step*

From this process (Figure 5.1), a table listing a single overall z-score for each step was constructed. In addition, the table also names and presents z-scores for any individual kinematic variables for which an overall z-score of at least 1.0 was obtained across the step. From this data it was possible to determine which steps were best able to detect overall deviations in kinematic variables between the professional and non-professional dancers, and more specifically, the type of kinematic variables for which each step could detect deviations.

The primary aim in designing the quantitative assessment tool was to establish a minimum number of ballet steps that could effectively detect deviations of the relevant kinematic variables from the "gold standard". This minimum number of steps was determined by investigating the effect of various numbers and combinations of steps on the rank order of the non-professional dancers in terms of the deviation of their kinematic data from that of the professional dancers. To do this the rank order of the overall z-scores (based across all nine kinematic variables) for the 14 non-professional dancers was compared between various pilot versions of the assessment tool, each of which contained a different number and combination of steps. A desirable outcome would be for high correlations of rank order between dancers to be obtained, whether all 14 steps were included in the assessment tool, or only a few steps, four for example. Such an outcome would indicate that fewer steps were equally as effective in detecting "incorrect" or less than ideal movement patterns, thus eliminating redundancy of data from inclusion of unnecessary steps, thereby reducing the time and cost for data collection and processing.

The various numbers and combinations of steps selected for each pilot version of the assessment tool were based on: the overall z-scores obtained for each step (*i.e.* how well each step was able to detect overall deviations in kinematic variables between the professional and non-professional dancers); and the type of individual kinematic variables for which each step detected deviations. Appropriate numbers of steps selected for inclusion in each pilot version were 14, 7 and 4. As indicted in Chapter 3, the group of 14 steps initially chosen for analysis contained two steps from each category of the 'Seven Movements of Dance' (Noverre, 1760). The seven steps selected in the first stage of step reduction therefore consisted of one step from each movement category. Each of the four steps selected for the final step reduction stage, also came from a different movement category. This process ensured that the assessment tool would contain diversity in the types of steps included. Consequently, to select the steps for the 7-step assessment tool, the step from each movement category with the highest overall z-score was chosen. For the 4-step assessment tool, one step from each of the four movement categories with the highest z-scores was selected. In addition, to investigate any possible effect of the actual number of steps, as opposed to the combination of steps, on the dancer rankings, another combination of four steps was selected for analysis. This additional 4-step assessment tool contained a group of steps selected from the remaining movement categories that were omitted from the initial 4-step tool.

5.2.3 Analysis of the Effect of the Number and Combination of Steps Included

To investigate the effect of the number and types of steps included in each pilot assessment tool, it was necessary to calculate an overall z-score for each non-professional dancer as an indication of the deviation of their kinematic data from the professional data. To do this, a single value representing the average z-score across all 20 time points was determined for each kinematic variable, for each step, for each dancer (Figure 5.2 – Phase 1). Then an average z-score for each kinematic variable was calculated across all the relevant steps *(i.e.* for 14 steps, 7 steps or 4 steps) included in each version of the assessment tool. Finally, for each pilot tool, an overall z-score was calculated by taking an average across the z-scores for all nine individual kinematic parameters. (Figure 5.2 – Phase 2). It was this overall z-score than was used to rank the dancers, with the highest z-score indicating greatest deviation from the “gold standard”.

For each different version of the assessment tool (*i.e.* 14-step tool, 7-step tool, or 4-step tool), a table was constructed in which the 14 non-professional dancers were listed in rank order from “best” (lower z-score) to “worst” (highest z-score). An additional table listed individual kinematic variables for which a dancer achieved a z-score of at least 1.0, thereby indicating the joint or segment movements for which each dancer’s data deviated by at least one standard deviation from the professional data. Dancer rank orders for each of the pilot assessment tools were compared using Spearman’s rank correlation coefficients. This analysis was conducted using SPSS™ version 18.0.

Phase 1

*** Dancer NP001 - Thorax Anterior/Posterior Tilt**

Time point	*Plié in First Position*	*Plié in Second Position*	↔	*Pirouette En Dehors*	*Pirouette En Dedans*
0%	z-score	z-score		z-score	z-score
↕					
100%	z-score	z-score		z-score	z-score
	Mean z-score for thorax ant/post tilt for Dancer NP001	**Mean z-score for thorax ant/post tilt for Dancer NP001**		**Mean z-score for thorax ant/post tilt for Dancer NP001**	**Mean z-score for thorax ant/post tilt for Dancer NP001**

A: *Phase 1 conducted for all 9 kinematic variables for all dancers

Phase 2

****Dancer NP001**

Kinematic Variables	*Pliés in First Position*	*Pliés in Second Position*	↔	*Pirouette En Dehors*	*Pirouette En Dedans*	**Mean z-score across all steps**
Thorax Ant/Post Tilt						
Thorax Side Tilt						
Pelvic Ant/Post Tilt						
Pelvic Obliquity						
Pelvic Ant/Post Tilt						
Hip Rotation						
Knee Flexion/Extension						
Ankle Plant/Dorsi Flexion						
Ankle Rotation						
						Overall mean z-score for Dancer NP001

C: Overall mean z-score taken across all kinematic variables

B: Mean z-score taken across all steps for each kinematic variable for Dancer NP001

D: **Phase 2 conducted for all 14 dancers

Phase 3

Dancer ID	Overall mean z-score for dancer (14 steps)	***Overall mean z-score for dancer (7steps)	***Overall mean z-score for dancer (4 steps)
NP001			
NP002			
NP003			
NP004			
NP005			
NP006			
NP007			
NP008			
NP010			
NP011			
NP012			
NP013			
NP014			
NP015			

E: ***Phase 1 and 2 repeated using only 7 steps, then again using only 4 steps

***Figure 5.2** Flow chart depicting process for calculation of overall mean z-score per dancer*

5.2.4 Development of the Assessment Tool Report

While it was important that the assessment report contain specific results for individual kinematic variables, it was also essential to indicate which fundamental biomechanical principle each variable related to. Therefore, the individual report constructed for each dancer consisted of a table listing all nine kinematic variables, the overall z-score achieved for each kinematic variable, and the fundamental principle with which each variable was associated, *e.g.* 'alignment', 'placement', 'turnout', or 'extension'. In receiving their results it would be important for individual dancers to get an indication of *how*, *i.e.* in which direction, their joint and segment movements differed from those of the professionals. Consequently, actual values of the z-scores (*i.e.* positive or negative), rather than absolute values were displayed. Z-scores of 1.0 or -1.0 were chosen as the threshold above or below which a kinematic variable would be considered to be "incorrect", and thus in need of attention. These cut-off values, that is a divergence of at least one standard deviation from the "gold standard" or "normal" population, represents a considerable proportion (*i.e.* at least 68%) of the population in question, and can therefore be considered as an appropriate cut-off value for the current study. Thus, for each variable for which a z-score of at least 1.0 or -1.0 was obtained, the general results table also contained comments indicating how this biomechanical parameter differed from the professional data, suggestions of possible causes, and ways in which the deviation could potentially be corrected.

To provide a detailed visual representation of the kinematic variables with z-scores of at least 1.0 or -1.0, data for each of these variables were presented in a graphical format. For these graphs, 'percentage complete movement' (*i.e.* 0-100%) was displayed along the horizontal axis, and degrees of joint or segment rotation appeared along the vertical axis. To indicate how individual data differed from the averaged professional data, curves for the mean professional values as well as one standard deviation above and one standard deviation below the mean were also included in the graphical display. To aid in data interpretation, generic stick figures depicting the various movement stages of each ballet step appeared alongside each graph. Basic subject and test date details were also included in the report. For the purposes of this thesis, all subject information data were included in a de-identifiable format, *e.g.* subject ID rather than subject name.

5.3 Results

5.3.1 Consideration of Steps for Inclusion in the Quantitative Assessment Tool

Movement category	Step	Overall z-score	Kinematic variables with z-score ≥ 1.0 (z-Score)			
			Alignment	Placement	Turnout	Extension
Bend (*Plié*)	*Plié in First Position*	0.910	Thorax Ant/Post Tilt (1.65)			
	Plié in Second Position	0.839	Thorax Ant/Post Tilt (1.56)			
Stretch (*Battement*)	*Battement Tendu Derriere*	0.794	Hip Rotation (1.28)			
	Battement Jeté to 45° Front	0.770	Hip Rotation (1.01)			
Rise (*Relevé*)	*Rise in First Position*	0.934	Pelvic Obliquity (1.25)	Ankle Rotation (1.20)	Pelvic Ant/Post Tilt (1.16)	Hip Rotation (1.07)
	Rise in Second Position	1.014	Ankle Rotation (1.51)	Pelvic Obliquity (1.34)	Hip Rotation (1.04)	Pelvic Ant/Post Tilt (1.03)
Jump (*Sauté*)	*Sauté s in First Position*	0.635				
	Temps Levé	0.762	Pelvic Obliquity (1.09)	Ankle Rotation (1.01)		
Glide (*Glissade*)	*Glissades Over*	0.614				
	Glissades Under	0.610				
Dart (*Elancé*)	*Jeté Ordinaire*	0.672				
	Grande Jeté Elancé En Avants	0.530				
Turn (*Tour*)	*Pirouette En Dedans*	0.444				
	Pirouette En Dehors	0.542	Ankle Rotation (1.07)			

Table 5.1 *Overall z-scores and deviant kinematic variables for each step and associated movement category.*

Table 5.1 presents the overall z-scores for each step, and the kinematic variables for which a z-score of at least 1.0 was obtained. It can be seen that the steps in the *relevé* category obtained the highest overall z-scores (0.934 and 1.014), and were able to detect deviations of at least one standard deviation (*i.e.* z-score ≥ 1.0) for the most kinematic variables. These steps detected deviations in kinematic variables that related to the principles of 'placement' (*i.e*. pelvic obliquity; pelvic anterior/posterior tilt) and 'turnout' (*i.e.* hip rotation; ankle rotation). The *pliés* ranked next in their ability to detect deviations in kinematic variables (z-scores: 0.910 and 0.839), followed by the *battements* (z-scores: 0.794 and 0.770. The *pliés* were able to detect deviations in 'alignment' (*i.e.* thorax anterior/posterior tilt), while the *battements* picked up deviations in 'turnout' (*i.e.* hip rotation). The *temps levé* from the *sauté* category could detect minor deviations in 'placement' (*i.e*. pelvic obliquity) and 'turnout' (*i.e.* ankle rotation), and although the *pirouette en dehors,* from the *tour* category, only obtained an overall z-score of 0.542 it too could detect deviations in 'turnout' (*i.e.* ankle rotation).

Based on the data in Table 5.1, the step from each movement category with the highest overall z-score was chosen for inclusion in the 7-step pilot assessment tool. Similarly, since highest z-scores were obtained for the *relevés*, *pliés*, *battements* and *sautés*, one step from each of these categories was chosen for inclusion in the 4-step tool. Since the individual z-scores for 'placement' (*i.e*. pelvic obliquity) and 'turnout' (*i.e.* ankle rotation) obtained by the *temps levé* were only just above 1.0 (1.09 and 1.01, respectively), and because deviations in 'placement' and 'turnout' were also detected by the *relevé* and *battements*, it was decided that an additional pilot assessment tool, containing only 3 steps would also be analysed. Thus, the 7-step assessment tool included:

1. *Plié in First Position*
2. *Battement Tendu Derriere*
3. *Rise in Second Position*
4. *Temps Levé*
5. *Glissades Over*
6. *Jeté Ordinaire*
7. *Pirouette En Dehors*

The 4-step assessment tool included:

1. *Plié in First Position*
2. *Battement Tendu Derriere*

3. *Rise in Second Position*
4. *Temps Levé*

And an additional 3-step assessment tool included:

1. *Plié in First Position*
2. *Battement Tendu Derriere*
3. *Rise in Second Position*

The other 4-step assessment tool, containing steps with the lowest z-scores included:

1. *Pirouette En Dedans*
2. *Grande Jeté Elancé En Avants*
3. *Glissades Under*
4. *Sautés*

Since an additional 3-step assessment tool using the 3 steps with the highest z-scores was investigated, an additional 3-step assessment tool, containing steps with the lowest z-scores, was also assessed. The steps included in this tool were:

1. *Pirouette En Dedans*
2. *Grande Jeté Elancé En Avants*
3. *Glissades Under*

5.3.2 Comparisons of Dancer Rankings when Including Different Numbers of Steps in the Assessment Tool

Table 5.2 shows the rank order of the 14 non-professional dancers according to their overall z-score across different numbers and combinations of steps. Table 5.3 summaries the results of the correlations (Spearman's *r*) and tests for significance (p-values) between the rank orders obtained for the different number and combination of steps used for each assessment tool.

Dancer ID	Dancer rank order by overall z-score across steps					
	14 steps	7 Steps	4 Steps	3 Steps	4 Other Steps	3 Other Steps
NP001	4	3	7	8	10	8
NP002	11	11	8	6	4	1
NP003	7	5	5	7	1	2
NP004	10	9	10	10	12	11
NP005	9	8	11	12	8	7
NP006	2	1	2	1	3	6
NP007	5	10	9	5	2	4
NP008	8	6	4	9	6	3
NP010	3	4	3	4	5	9
NP011	6	7	6	3	9	12
NP012	12	13	13	13	11	10
NP013	13	12	12	11	13	13
NP014	1	2	1	2	7	5
NP015	14	14	14	14	14	14

***Table 5.2** Dancer rank order by overall z-score across different numbers and combinations of steps. Rank 1 = "best" dancer (i.e. lowest z-score)..... Rank 14 = "worst" dancer (i.e. highest z-score).*

Assessment Tool A	Assessment Tool B	Spearman's rho (r)	p value
14 steps	7 steps	0.908**	0.000
14 steps	4 steps	0.868**	0.000
14 steps	3 steps	0.851**	0.000
14 steps	4 other steps	0.582*	0.029
14 steps	3 other steps	0.385	0.175
7 steps	4 steps	0.903**	0.000
7 steps	3 steps	0.732**	0.003
7 steps	4 other steps	0.503	0.067
7 steps	3 other steps	0.389	0.169
4 steps	3 steps	0.859**	0.000
4 steps	3 other steps	0.525	0.054
4 steps	4 other steps	0.644*	0.013
3 steps	3 other steps	0.415	0.140
3 steps	4 other steps	0.657*	0.011
4 other steps	3 other steps	0.851**	0.000

***Table 5.3** Spearman's correlation coefficients (r) and p-values for correlation of Assessment tool A with Assessment tool B.*
***Correlation is significant at the 0.01 levé l.*
**Correlation is significant at the 0.05 levé l.*

Table 5.3 depicts highly significant correlations ($p < 0.01$) for comparison of dancer rank orders from use of 14, 7, 4 and 3 steps in the assessment tool. However, correlation coefficients were lower when comparing the other combinations of 3 or 4 steps (*i.e.* the 3 or 4 steps that did not independently detect deviations in any of the relevant kinematic variables). For example, correlations were not significant at the 0.01 level for comparison between use of 14, 7, 4, or 3 steps in the assessment tool, with either the 3 other steps, or 4 other steps. The data therefore indicate that it is the type of step included in the assessment tool, rather than the number of steps, that influence the rank order of dancers.

As indicated in Table 5.2, dancer NP015 was the lowest ranked dancer when considering all pilot assessment tools, and dancer NP006 ranked first or second when using the majority of assessment tools. Given that the number or combination of steps did not greatly affect the rank order for these dancers, it is interesting to examine if different numbers and combinations of steps included in the tool would enable it to detect or highlight differences in the z-scores obtained for individual kinematic variables. The next section therefore presents results for the individual kinematic variables for which z-scores of at least 1.0 were obtained, and displays these variables in relation to their associated fundamental biomechanical principle.

5.3.3 Analysis of the Effect of the Number and Combination of Steps on Z-Scores for Individual Kinematic Variables

Table 5.4 displays the overall z-scores achieved by each dancer when using each different pilot version of the quantitative assessment tool (*i.e.* 14-step, 7-step, 4-step, and 3-step). The table also displays the individual kinematic variables for which a dancer achieved a z-score of at least 1.0, thereby indicating the joint or segment movements for which each dancer's data deviated by at least one standard deviation from the professional data. These variables have been colour coded to give a visual representation of the fundamental principle that they each relate to.

Dancer ID	Assessment Tool	Overall z-score	Kinematic variables with z-score ≥ 1.0 (z-score)				
			Alignment	Placement	Turnout	Extension	
NP001	14 steps	0.679	Thorax Ant/ Post Tilt (1.27)				
	7 steps	0.658	Thorax Ant/Post Tilt (1.22)				
	4 steps	0.841	Thorax Ant/Post Tilt (1.80)	Knee Flexion/ Extension (1.07)	Thorax Side Tilt (1.04)		
	3 steps	0.858	Thorax Ant/Post Tilt (1.93)	Knee Flexion/ Extension (1.18)			
	4 other steps	0.551					
	3 other steps	0.530					
NP002	14 steps	0.762	Ankle Rotation (1.57)	Hip Rotation (1.32)			
	7 steps	0.800	Ankle Rotation (1.71)	Hip Rotation (1.51)			
	4 steps	0.852	Ankle Rotation (2.10)	Hip Rotation (1.47)	Pelvic Obliquity (1.01)		
	3 steps	0.840	Ankle Rotation (2.32)	Hip Rotation (1.52)	Pelvic Obliquity (1.10)		
	4 other steps	0.501					
	3 other steps	0.410					
NP003	14 steps	0.697	Pelvic Ant/Post Tilt (1.34)				
	7 steps	0.713	Pelvic Ant/Post Tilt (1.47)				
	4 steps	0.811	Pelvic Ant/Post Tilt (2.00)				
	3 steps	0.854	Pelvic Ant/Post Tilt (2.26)				
	4 other steps	0.438					
	3 other steps	0.431					

***Table 5.4** Dancer overall z-scores per assessment tool, and kinematic variables with z-scores ≥ 1.0*

Dancer ID	Assessment Tool	Overall z-score	Kinematic variables with z-score ≥ 1.0 (z-score) Alignment / Placement / Turnout / Extension				
NP004	14 steps	0.758	Ankle Rotation (1.41)	Pelvic-Thorax Rotation (1.27)			
	7 steps	0.765	Ankle Rotation (1.53)	Pelvic-Thorax Rotation (1.19)			
	4 steps	0.892	Ankle Rotation (1.66)	Pelvic-Thorax Rotation (1.37)	Thorax Ant/Post Tilt (1.11)		
	3 steps	0.909	Pelvic-Thorax Rotation (1.64)	Ankle Rotation (1.56)	Thorax Ant/Post Tilt (1.11)	Thorax Side Tilt (1.09)	
	4 other steps	0.605	Pelvic-Thorax Rotation (1.20)	Ankle Rotation (1.19)			
	3 other steps	0.540	Ankle Rotation (1.06)				
NP005	14 steps	0.732	Pelvic Obliquity (1.33)				
	7 steps	0.755	Pelvic Obliquity (1.27)	Thorax Ant/Post Tilt (1.13)	Hip Rotation (1.03)		
	4 steps	0.918	Pelvic Obliquity (1.98)	Thorax Ant/Post Tilt (1.54)	Hip Rotation (1.09)		
	3 steps	0.999	Pelvic Obliquity (2.52)	Thorax Ant/Post Tilt (1.38)	Hip Rotation (1.28)		
	4 other steps	0.542					
	3 other steps	0.529					
NP006	14 steps	0.599	Pelvic Obliquity (1.04)				
	7 steps	0.589	Pelvic Obliquity (1.10)				
	4 steps	0.644	Pelvic Obliquity (1.54)				
	3 steps	0.680	Pelvic Obliquity (1.96)				
	4 other steps	0.492					
	3 other steps	0.497					

Table 5.4 (continued) *Dancer overall z-scores per assessment tool, and kinematic variables with z-scores ≥ 1.0*

Dancer ID	Assessment Tool	Overall z-score	Kinematic variables with z-score ≥ 1.0 (z-score) Alignment Placement Turnout Extension				
NP007	14 steps	0.681	Ankle Dorsi/ Plantar Flex (1.16)				
	7 steps	0.766	Ankle Dorsi/ Plantar Flex (1.46)	Thorax Ant/Post Tilt (1.17)			
	4 steps	0.853	Thorax Ant/Post Tilt (1.59)	Ankle Dorsi/ Plantar Flex (1.40)			
	3 steps	0.839	Thorax Ant/Post Tilt (1.72)	Ankle Dorsi/ Plantar Flex (1.47)	Pelvic Ant/ Post Tilt (1.03)		
	4 other steps	0.492					
	3 other steps	0.486					
NP008	14 steps	0.703	Pelvic Obliquity (1.28)				
	7 steps	0.715	Pelvic Obliquity (1.27)				
	4 steps	0.809	Pelvic Obliquity (1.86)				
	3 steps	0.866	Pelvic Obliquity (2.15)				
	4 other steps	0.523					
	3 other steps	0.462					
NP010	14 steps	0.628					
	7 steps	0.668					
	4 steps	0.741					
	3 steps	0.786	Pelvic Ant/Post Tilt (1.08)				
	4 other steps	0.505					
	3 other steps	0.536					

Table 5.4 (continued) *Dancer overall z-scores per assessment tool, and kinematic variables with z-scores ≥ 1.0*

Dancer ID	Assessment Tool	Overall z-score	Kinematic variables with z-score ≥ 1.0 (z-score)				
			Alignment	Placement	Turnout	Extension	
NP011	14 steps	0.691	Ankle Rotation (1.17)	Hip Rotation (1.04)			
	7 steps	0.751	Ankle Rotation (1.46)	Hip Rotation (1.03)			
	4 steps	0.811	Ankle Rotation (1.65)	Hip Rotation (1.20)			
	3 steps	0.735	Ankle Rotation (1.52)	Hip Rotation (1.43)			
	4 other steps	0.546					
	3 other steps	0.559					
NP012	14 steps	0.785	Pelvic Obliquity (1.10)	Hip Rotation (1.01)			
	7 steps	0.881	Pelvic Obliquity (1.18)	Thorax Ant/Post Tilt (1.15)	Hip Rotation (1.12)		
	4 steps	1.032	Thorax Ant/Post Tilt (1.71)	Pelvic Obliquity (1.57)	Pelvic Ant/ Post Tilt (1.33)	Ankle Rotation (1.25)	Hip Rotation (1.19)
	3 steps	1.153	Thorax Ant/Post Tilt (2.11)	Pelvic Obliquity (1.71)	Pelvic Ant/ Post Tilt (1.48)	Hip Rotation (1.30)	Ankle Rotation (1.17)
	4 other steps	0.594					
	3 other steps	0.539					
NP013	14 steps	0.824	Ankle Rotation (1.42)	Pelvic Obliquity (1.00)			
	7 steps	0.849	Ankle Rotation (1.55)	Pelvic Obliquity (1.07)			
	4 steps	0.972	Ankle Rotation (1.53)	Pelvic Obliquity (1.52)	Knee Flexion/ Extension (1.08)	Hip Rotation (1.03)	
	3 steps	0.967	Ankle Rotation (1.42)	Pelvic Obliquity (1.32)	Hip Rotation (1.30)	Knee Flexion/ Extension (1.14)	
	4 other steps	0.702	Ankle Rotation (1.40)				
	3 other steps	0.681	Ankle Rotation (1.43)				

Table 5.4 (continued) *Dancer overall z-scores per assessment tool, and kinematic variables with z-scores ≥ 1.0*

Dancer ID	**Step Combinations**	**Overall z-score**	**Kinematic variables with z-score ≥ 1.0 (z-score)** Alignment / Placement / Turnout / Extension				
NP014	14 steps	0.573					
	7 steps	0.598					
	4 steps	0.635					
	3 steps	0.681	Thorax Side Tilt (1.16)				
	4 other steps	0.535					
	3 other steps	0.496					
NP015	14 steps	0.937	Ankle Rotation (1.74)	Hip Rotation (1.26)	Thorax Side Tilt (1.04)		
	7 steps	0.974	Ankle Rotation (1.79)	Hip Rotation (1.36)	Pelvic-Thorax Rotation 1.02)		
	4 steps	1.114	Ankle Rotation (1.91)	Hip Rotation (1.57)	Thorax Side Tilt (1.20)	Pelvic Ant/Post Tilt (1.18)	Ankle Dorsi/ Plantar Flex (1.16)
	3 steps	1.185	Ankle Rotation (2.11)	Hip Rotation (1.73)	Thorax Side Tilt (1.54)	Pelvic Ant/Post Tilt (1.31)	Ankle Dorsi/ Plantar Flex (1.12)
	4 other steps	0.751	Ankle Rotation (1.49)				
	3 other steps	0.709	Ankle Rotation (1.58)				

Table 5.4 (continued) *Dancer overall z-scores per assessment tool, and kinematic variables with z-scores ≥ 1.0*

Table 5.4 indicates that when using different versions of the assessment tool (*i.e.* different numbers and combinations of steps), there are some notable differences in the individual kinematic variables for which deviations of greater than one standard deviation were detected. That is, the number and combination of steps did affect the ability of the assessment tools to detect deviations in the kinematic variables that relate to the four fundamental principles of classical ballet technique. For 13 of the 14 non-professional dancers analysed, the most kinematic variables were detected as being "incorrect" (*i.e.* z-score ≥1.0) when only 3 steps were included in the assessment tool. It was the 3 steps (*i.e. grand plié in first position; battement tendu derriere; rise in second position),* that in the inter-step analysis (Table 5.1) independently achieved the highest overall z-values (*i.e.* greatest deviation) rather than the 3 steps (*i.e. glissades under; grand jeté elancé en avants; pirouette en dedans)* that achieved the lowest overall z-values, for which the most deviations were detected for each dancer. Table 5.4 also indicates that the least number of kinematic variables were detected as being "incorrect" (*i.e.* z-score ≥ 1.0), when these other 3 steps (*i.e. glissades under; grand jeté elancé en avants; pirouette en dedans)* were used. This result indicates that it is the type of steps, rather than the number of steps, included in the assessment tool that affect the tool's ability to detect deviations in the kinematic variables that relate to the fundamental principles of classical ballet technique.

5.3.4 Sample Assessment Tool Report

Since the 3-step assessment tool containing the *grand plié in first position, battement tendu derriere*, and *rise in second position* was able to detect deviations in the fundamental principles of classical ballet technique better than all other numbers and combinations of steps, this tool was therefore used to create sample assessment reports for each of the 14 non-professional dancers whose data were used during this analysis.

The following pages contain an example assessment report for dancer NP015, who was ranked lowest for all assessment tools that were examined. As indicated in the report, deviations in multiple kinematic variables were detected for dancer NP015. These variables related to all four fundamental principles of classical ballet technique, and included ankle rotation and hip rotation ('turnout'), thoracic side tilt ('alignment'), pelvic anterior tilt ('placement'), and ankle plantarflexion ('extension').

Dancer ID: NP015
Date: 6/10/2009

Classical Ballet Technique Quantitative Assessment Report

Dancer ID: NP015
Dancer DOB: 21/04/1991
Assessment Date: 6/10/2009

This report summarises results for three-dimensional (3D) joint movements for the thorax, pelvis, hips, knees and ankles during performance of the following classical ballet steps:

- *Grand plié in first position*
- *Battement tendu derriere*
- *Rise in second position*

Section 1 - General Results Summary

Principle	Kinematic Measurement Variable	Overall z-score	Comments
Alignment	Thoracic Anterior/Posterior Tilt	0.79	• Satisfactory.
	Thoracic Side Tilt	-1.54*	• Increased thoracic side tilt towards left side. • Possibly due to functional or structural scoliosis, and/or weak abdominal and spinal musculature. • Work to strengthen abdominal and spinal musculature.
Placement	Pelvic Anterior/Posterior Tilt	1.31*	• Increased anterior pelvic tilt. • Possibly due to functional or structural increased lumber lordosis and/or weak abdominal musculature. • Work to strengthen abdominals and lengthen the coccyx (tailbone) down towards the floor.
	Pelvic Obliquity	0.60	• Satisfactory.
	Pelvic-Thoracic Rotation	0.71	• Satisfactory.
Turnout	Hip External Rotation	1.73*	• Decreased external hip rotation. • Possibly due to functional or structural limitations within the hip joint. • Work to actively engage the deep rotators of hip
	Ankle External Rotation	2.11*	• Decreased external ankle rotation. • Possibly due to functional or structural limitations within the ankle joint. • Work to strengthen the musculature across the ankle to achieve the desired foot and ankle position and line.
Extension	Knee Extension	0.76	• Satisfactory.
	Ankle Plantarflexion	1.12*	• Decreased ankle plantarflexion. • Possibly due to functional or structural limitations within the ankle joint. • Work to strengthen the ankle plantarflexors and the intrinsic muscles of the foot.

Overall z-score calculated as average across all analysed steps.
**z-score ≥ 1 or z-score ≤ -1: Joint/segment movement is at least one standard deviation from mean value for professional ballet dancers, and thus in need of attention or correction.*
-1 < z-score < 1: Within satisfactory range.

Page 1

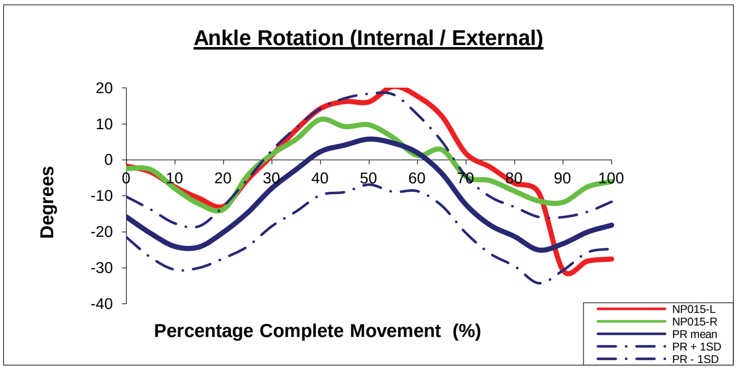
Dancer ID: NP015
Date: 6/10/2009

<u>Section 2 – Graphical Data for Variables in Need of Attention</u>

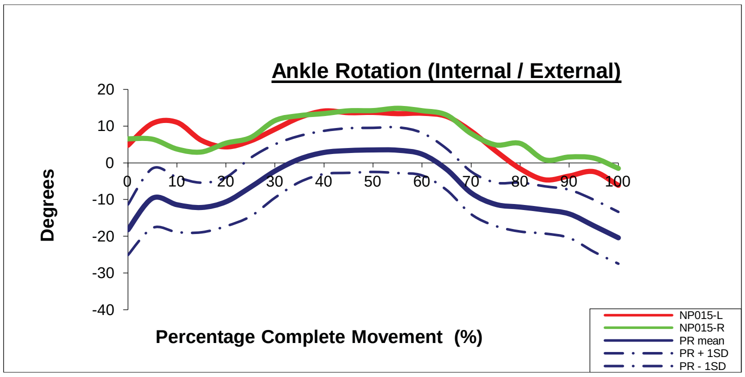
1. ***<u>Ankle Rotation</u> (Overall z-score = 2.11)***

- Decreased external ankle rotation

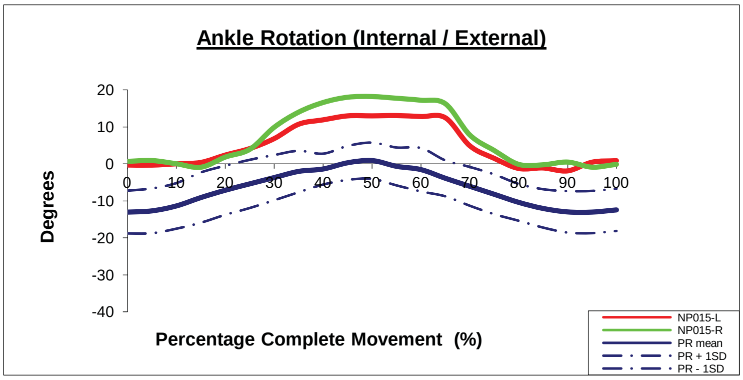
Grand Plié in First Position



Battement Tendu Derriere



Rise in Second Position



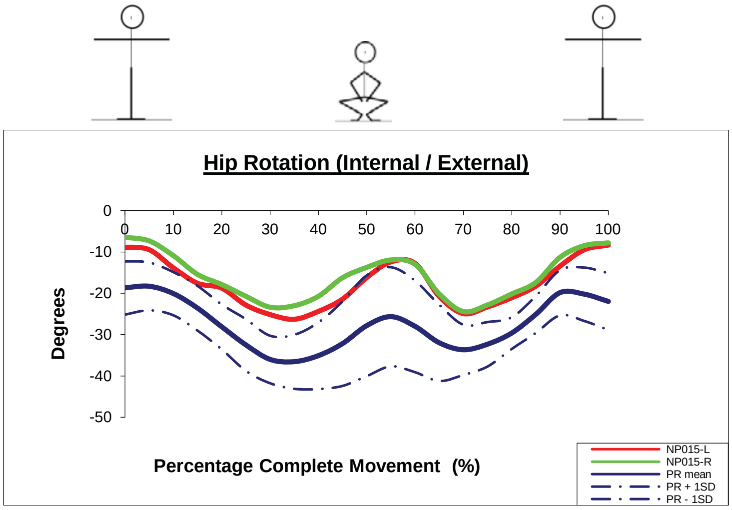
Page 2

Dancer ID: NP015
Date: 6/10/2009

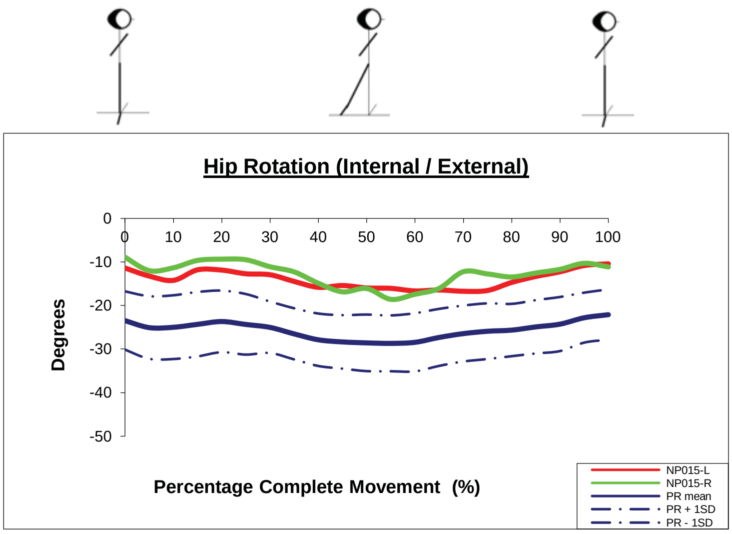
2. ***Hip Rotation* (Overall z-score = 1.73)**

- Decreased external hip rotation

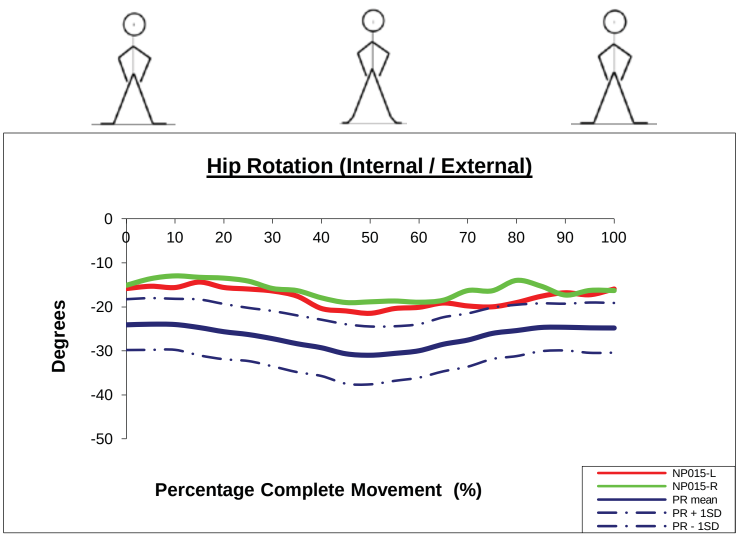
Grand Plié in First Position



Battement Tendu Derriere



Rise in Second Position



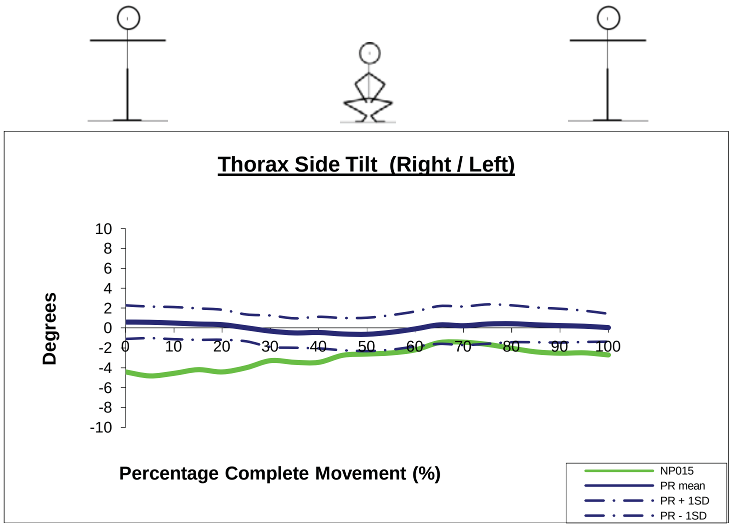
Page 3

Dancer ID: NP015
Date: 6/10/2009

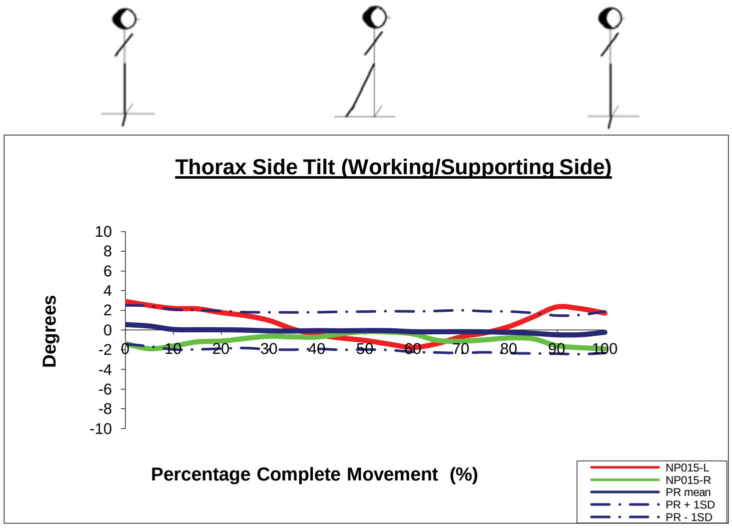
3. *Thoracic Side Tilt* (Overall z-score = -1.54)

- Increased thoracic side tilt towards left side

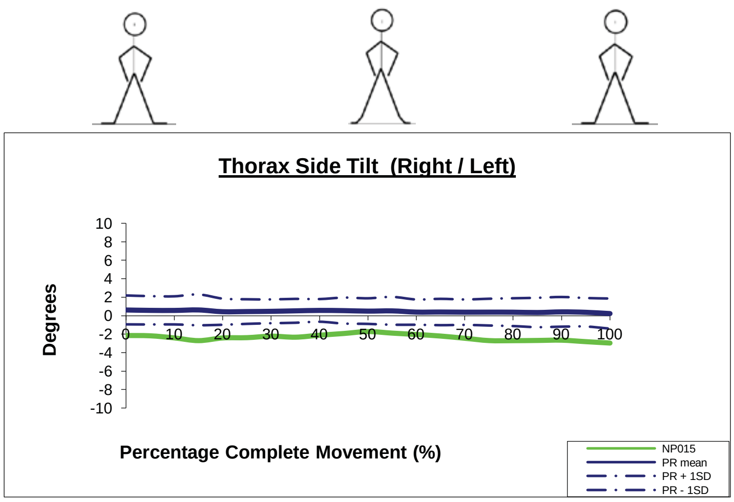
Grand Plié in First



Battement Tendu Derriere



Rise in First Position



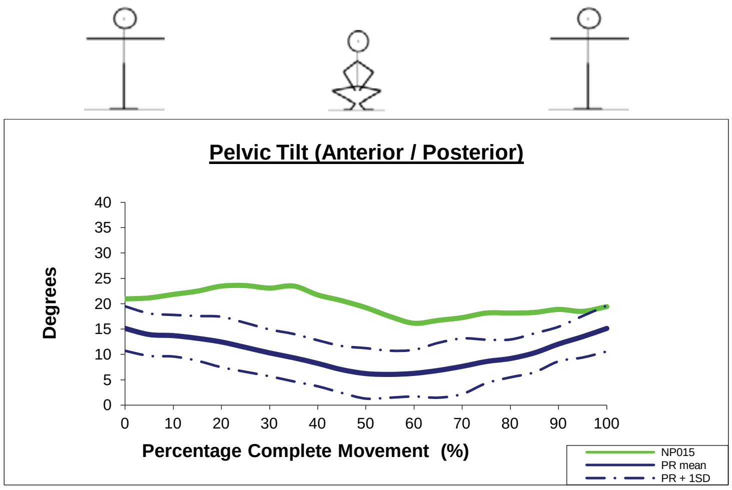
Page 4

Dancer ID: NP015
Date: 6/10/2009

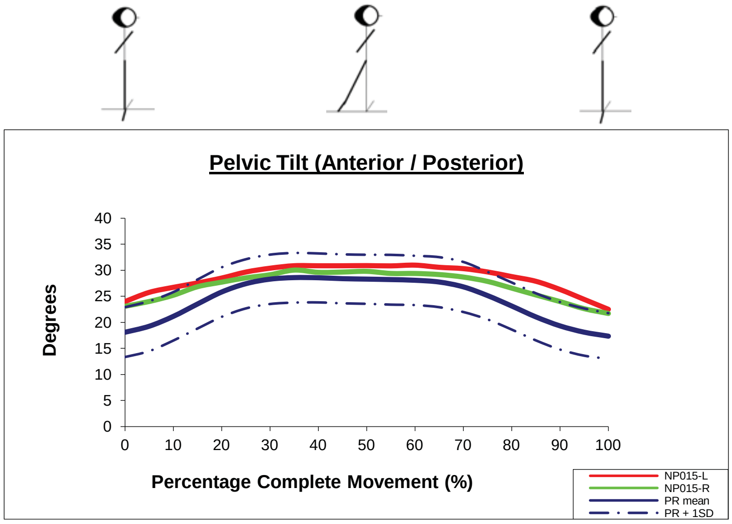
4. *Pelvic Anterior/Posterior Tilt* (Overall z-score = 1.31)

- Increased anterior pelvic tilt

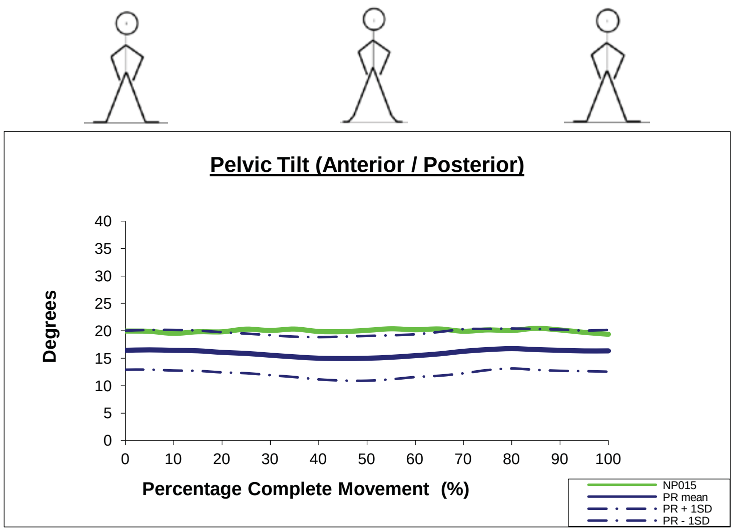
Grand Plié in First Position



Battement Tendu Derriere



Rise in Second Position

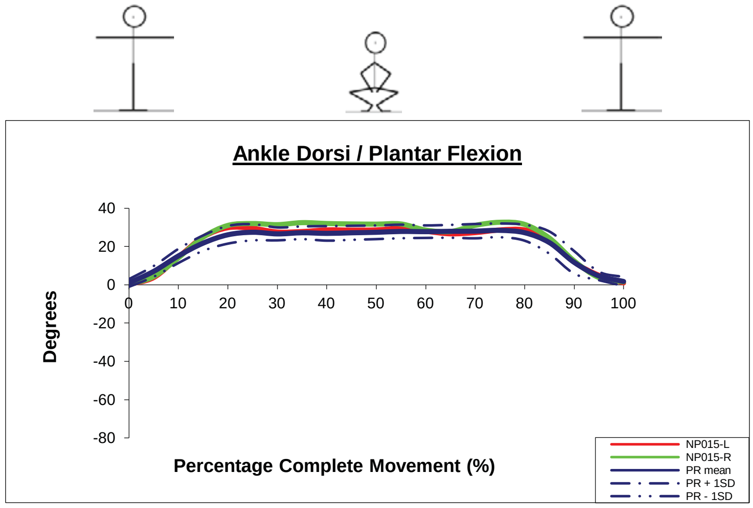


Page 5

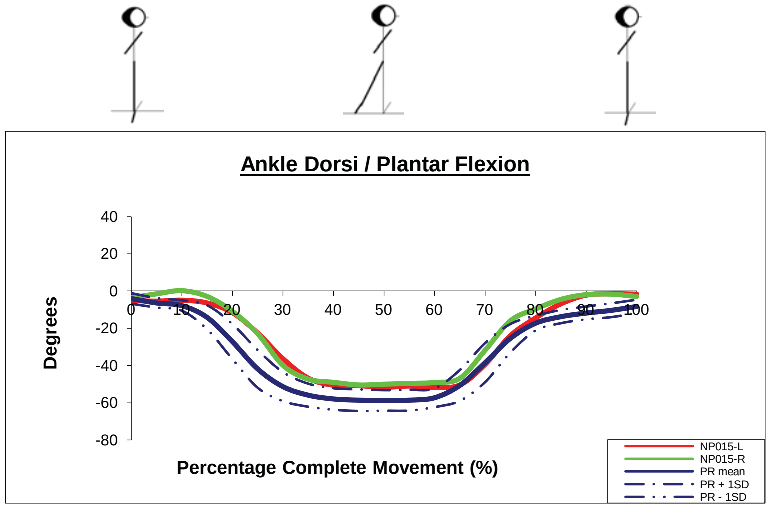
Dancer ID: NP015
Date: 6/10/2009

5. ***Ankle Plantarflexion*** ***(Overall z-score = 1.12)***
- Decreased ankle plantarflexion

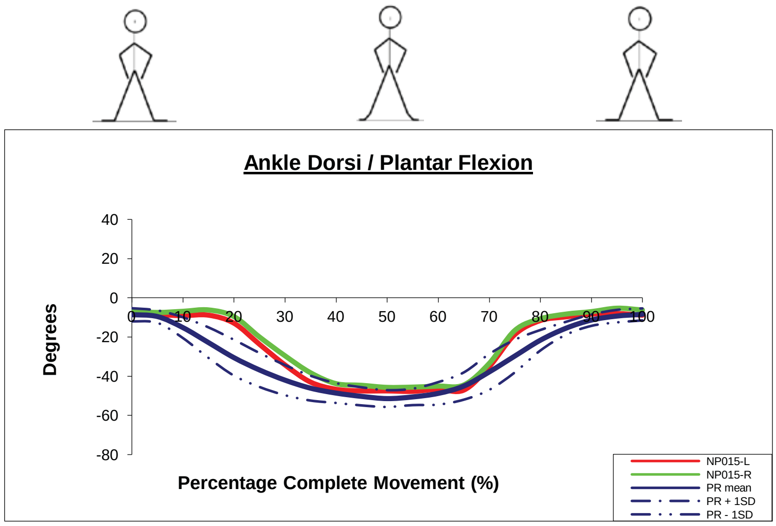
Grand Plié in First Position



Battement Tendu Derriere



Rise in Second Position



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5.4 Discussion

In this chapter the minimum number and appropriate combination of ballet steps for inclusion in a quantitative assessment tool for classical ballet technique were identified. This process eliminated redundancy of data for inclusion in the tool, thereby making data collection and processing more cost and time efficient. This analysis procedure initially required investigation of the ability of particular movement categories or steps to detect deviations in kinematic variables between professional and non-professional dancers.

5.4.1 Identification of Steps for Inclusion in the Assessment Tool

The *pliés*, *battements*, and *rises* were the three movement categories that detected the most kinematic deviations. Specifically, *rises* detected differences in the principles of 'placement' (*i.e.* pelvic anterior/posterior tilt and pelvic obliquity) and 'turnout' (*i.e.* hip rotation and ankle rotation), *battements* also picked up differences in 'turnout' (*i.e*. hip rotation), while the *pliés* were sensitive to differences in 'alignment' (*i.e.* thorax anterior/posterior tilt). In Chapter 3, a similar analysis was conducted based on kinematic data obtained from only the start and peak of each step, rather than from the whole step, as in the current chapter. Comparison of data from each method of analysis reveals that the same three movement categories were identified as being most sensitive to kinematic differences, and in fact for the most part identified differences in the same kinematic variables. Some notable differences were that when only assessing the starts and peaks, the *rises* did not detect differences in 'placement' as well as 'turnout', as was the case for analysis of the whole step. However for the *battements*, analysis of only the start and peaks revealed differences in the principle of 'extension' (knee extension), in addition to 'turnout'. Both methods of analysis revealed that the *pliés* were effective in picking up differences in 'alignment' (*i.e.* thorax anterior/posterior tilt) but no other kinematic variables. The finding that the same three steps are most sensitive to kinematic deviations whether only the start and peak or the whole step is analysed, adds support for their inclusion in the quantitative assessment tool.

5.4.2 Affect of the Number and Type of Steps Included in the Assessment Tool

Before simply opting to include only three steps in the assessment tool, it was necessary to investigate how reducing the number of steps would affect the rank order of non-professional dancers as well as the kinematic deviations detected for individual dancers. Spearman's rank order correlation coefficients revealed significant correlations between rank order of the 14 non-professional dancers when comparing use of 14 steps, 7 steps, 4 steps or just the 3 steps specified above. This result indicates that exclusion of 11 steps from the assessment tool does not significantly affect the ranking of the non-professional dancers against the "gold standard" practical data produced by the professionals. Interestingly, despite no significant differences in rank order, the reduction in steps to only three did influence the specific kinematic variables for which deviations were detected for each dancer. An absolute z-score of greater than 1.0 was used as the threshold for a kinematic variable being identified as deviating from the "gold standard" and thus being "incorrect". For all but one of the 14 non-professional dancers, the most "incorrect" kinematic variables were detected when only 3 steps were included in the assessment tool, thereby proving the 3-step tool to be the most sensitive to kinematic deviations.

To examine the possibility that it was the number, rather than type of steps included in the assessment tool, that influenced the number of "incorrect" variables detected, additional analysis were conducted using combinations of 3 and 4 "other" steps. The ranks orders of dancers obtained from an assessment tool based on these "other" steps did not correlate well with the 14, 7, 4 or 3 steps used in the initial versions of the tool, and interestingly, use of only these 3 or 4 "other" steps resulted in detection of the fewest number of "incorrect" variables for all 14 dancers. This result ruled out the possibility that it was the number of steps that was affecting how many "incorrect" variables were identified. Therefore, a reduction in the number of steps included in the tool to only three does not alter the rank order of dancers, and in fact increases the sensitivity of the assessment tool at detecting deviations in the relevant variables, as long as the most appropriate steps are selected.

5.4.3 Comparison With Other Tools Used For Assessment of Classical Ballet Technique

Other examples of quantitative assessment tools for classical ballet technique were not identified in the academic literature. Comparison of the newly developed tool with existing quantitative tools is therefore not possible. However, some assessment tools based on qualitative analysis were identified for classical ballet technique (Liederbach, 1997; Molnar and Esterson, 1997; Gibbs *et al.*, 2006; Potter and Baas, 2011). Interestingly, there were similarities between the steps included in these qualitative assessment tools and those systematically selected for inclusion in the quantitative assessment tool developed in the current study. Nine different ballet steps were included across the four qualitative assessment tools identified, these are listed in Table 5.5. Of these steps, three steps (*port de bras; passé; developpé*) were not included in the analyses conducted in any of the phases of the current project. Of those that were analysed in the current project (*plié; battement tendu; rise; sauté; jeté; pirouette),* the *plié, battement tendu* and *rise* were the steps most frequently included in the four qualitative assessment tools for classical ballet technique, and correspond directly with the steps selected for the quantitative assessment tool.

Step	Molnar and Esterson (1997)	Liederbach (1997)	Gibbs *et al.* (2006)	Potter and Bass (2011)	Total "✓"
Plié	✓	✓	✓	×	3
Battement Tendu	✓	×	×	✓	2
Rise	✓	×	✓	×	2
Port de Bras	✓	×	×	✓	2
Passé	✓	×	×	×	1
Developpé	✓	×	×	✓	2
Sauté	×	✓	×	×	1
Jeté	×	✓	×	×	1
Pirouette	×	✓	×	×	1

Table 5.5 *Classical ballet steps in included qualitative screening tools.*
✓step included in assessment tool; × step not included in assessment tool.

Although similarities were found between the steps included in the qualitative and quantitative analysis methods, there are some differences in the specific elements each step was used to assess. For example, the current study found that the *plié* was effective in detecting deviations in ‘alignment’, specifically in thoracic anterior/posterior tilt, however Gibbs *et al.* (2006) described “lumbo/pelvic stability, mal-alignment of the knee with respect to the feet, and the position of the ankle joint” to be the crucial elements to look for when qualitatively assessing the *plié*. Gibbs *et al.* (2006) also listed these same elements as being important factors when observing the *rise*. With respect to the *rise* these critical features are in closer agreement with some of the kinematic variables best detected by the *rise* in the quantitative assessment tool (*i.e.* pelvic anterior/posterior tilt and ankle rotation). The critical features described by the authors of the other qualitative assessment tools were more ambiguous and could not be easily translated into specific kinematic variables. Molnar and Esterson (1997) reported that “elements such as ‘alignment’ and ‘stability’ should be assessed”, and Potter and Baas (2011) state that “it is essential to ‘look’ for attributes of faulty movement patterning”. Despite some uncertainties as to the specific reasons for inclusion of some of the steps in the qualitative assessment tools, the finding that the three steps chosen for inclusion in the newly developed quantitative tool are also commonly included in existing qualitative assessment tools, provides encouragement for the *content validity* of the new quantitative tool.

5.4.4 Potential Use of the Quantitative Assessment Tool

The qualitative assessment tools described in the previous section typically form part of larger screening tools used to assess the overall health, physical condition and potential injury risk of dancers as they enter into a dance training program or commence employment with a professional dance company. The baseline data obtained through these screenings can be used as a reference to assess each dancer’s progression toward optimal conditioning and development of optimal technique for their dance career (Solomon, 1997). Data from multiple time points are thus typically compared during a dancer’s affiliation with a particular company or educational institution. A similar model of use could also be adopted for the quantitative tool developed in the current study. That is, it could be used to systematically measure and record the progression of classical ballet technique for individual dancers across education semesters or dance company seasons. Such a tool could help assess the effectiveness of the implementation of specific training programs, or in fact the influence of different dance teachers on the development of correct classical ballet technique. Using data obtained from the non-professional dancers who participated in this research project, Figure 5.3 provides an example of the way in which data from a single cohort of dancers (*e.g.* first year entry into a dance program or company) could be presented to provide an overall indication of the technical competency of the group. The numbers displayed in each bar represent the z-scores for each kinematic variable for each dancer. The data are colour coded with respect to the kinematic variables and the fundamental principle with which each variable is associated. A sum of the z-scores across all dancers in the cohort for each kinematic variable is listed in the legend. For each individual dancer, higher z-scores and more variables displayed on the graph indicate less competent technique, while the absence of any bars next to a dancers ID indicate excellent technique for that dancer.

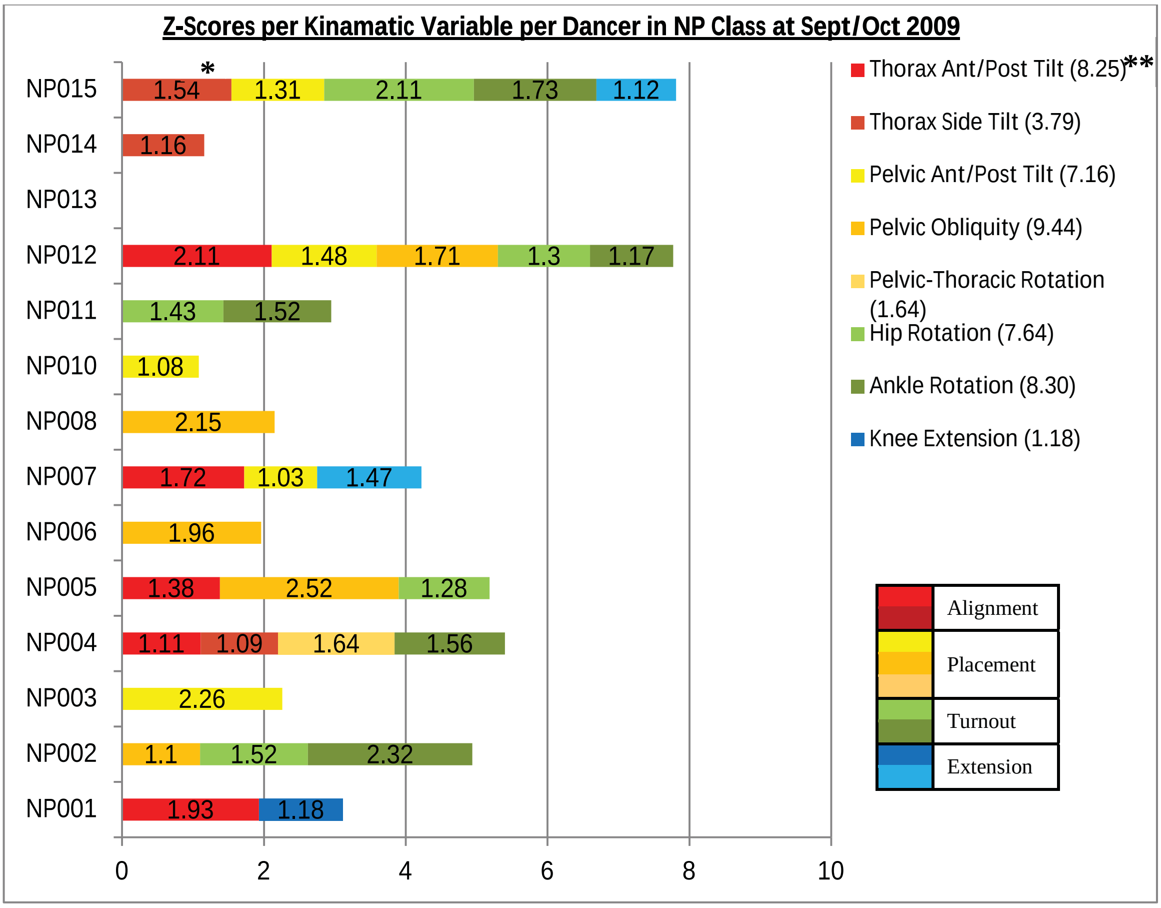

Figure 5.3 *Example of assessment results for a cohort of dancers for a specific time point. * Z-score for each kinematic variable per dancer. ** Cumulative z-score per each kinematic variable across all dancers. Lower z-scores and fewer kinematic variables indicate better technique.*

From the data presented in Figure 5.3, dancer NP013 has the best technique, with no deviations or “incorrect” kinematic variables identified. Dancers NP015 and NP012 however, have the least competent technique with “incorrect” data being detected for 5 of the 9 kinematic variables assessed. This figure also indicates that across the group the variables with the greatest deviations from the "gold standard" were pelvic obliquity, thoracic anterior/posterior tilt and ankle rotation. This style of presentation is therefore useful for comparing classical ballet technique between dancers, but it can also potentially be used to compare technique between groups. Given that a particular group or class of dancers often have the same teacher for a whole semester or season, inter-group comparisons could enable investigation of the effects of individual teachers on particular kinematic variables across the whole group, across multiple time points.

In addition to inter-dancer and inter-group comparisons, the data obtained from the quantitative tool could also be used to assess the progression of technique of individual dancers across multiple time points. Figure 5.4 provides an example of how quantitative data could be presented to allow for efficient analysis of changes in an individual dancer's technical competency over time. Data from Dancer NP015 were used for the Term 1 2009 time point, but it should be pointed out that all data moving forward from this time point is hypothetical and has been added to the graph for the purposes of demonstrating potential uses of the tool.

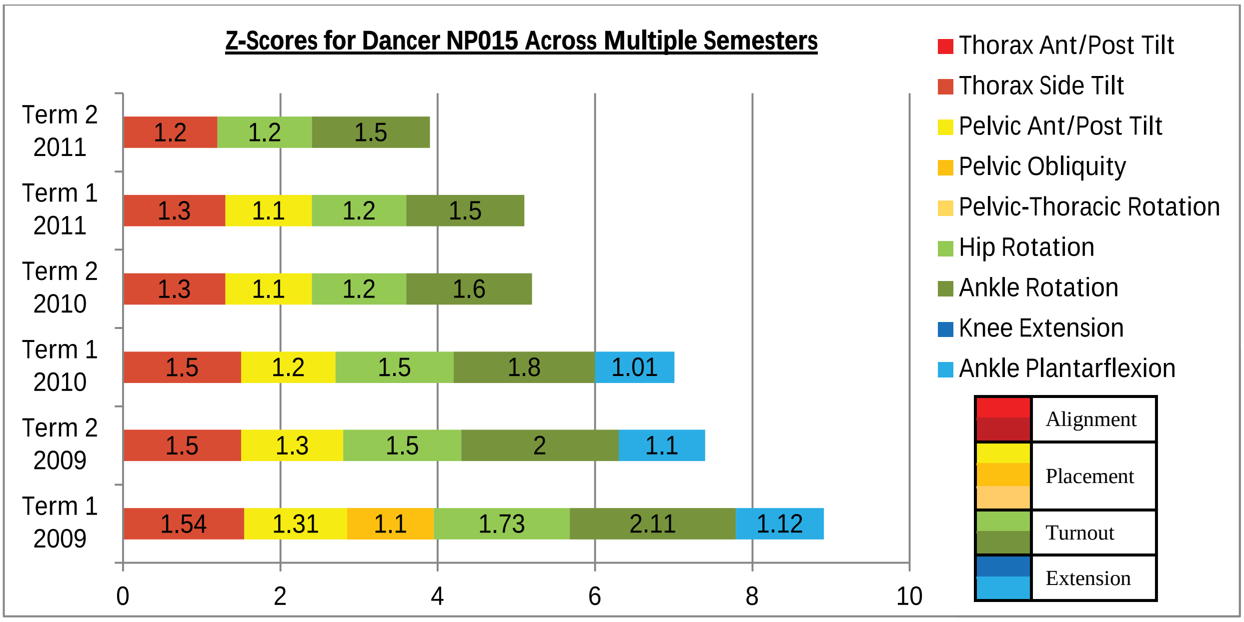

Figure 5.4 *Example of assessment results by time point for individual dancer NP015. * Z-score for each kinematic variable time point. Lower z-scores and fewer kinematic variables indicate better technique. (Data for Term 2 2009 – Term 2 2011 are fictional).*

In this hypothetical example, the reduction in the z-scores and number of kinematic variables for each successive time point indicates that this dancer has improved her classical ballet technique across the 6 semesters displayed. Figure 5.4 indicates that on her initial assessment (Term 1, 2009), Dancer NP015 had problems, or deviations from the "gold standard", in thorax side tilt, pelvic anterior/posterior tilt, pelvic obliquity, hip rotation, ankle rotation, and ankle plantarflexion. The highest z-scores for hip rotation and ankle rotation at this time point indicate that 'turnout' is the fundamental principle for which this dancer exhibits the most deviation. Hypothetically, by her final semester (Term 2, 2011) this dancer made considerable improvements in ankle plantarflexion, pelvic obliquity, and pelvic anterior/posterior tilt, as indicted by omission of these variables from the graph at this final time point. Some improvements in the remaining kinematic variables are also indicated by the decrease in z-scores compared to the baseline data. This style of data presentation therefore has the potential to provide encouraging information to individual dancers on their technical development, and to provide a clear and concise summary of specific areas in which a dancer and his/her teacher may need to focus their attention in order to improve classical ballet technique.

5.4.5 Limitations

As was the case for Chapter 4, the main limitation associated with this study and the development of the quantitative assessment tool is the number of professional dancers from which "gold standard" kinematic data were obtained. Data averaged from 12 professional dancers were used as the practical benchmark for indication of "correct" classical ballet technique. Inclusion of data from more professional ballet dancers would add to the validity of the tool, in that the variability amongst the reference data would potentially be reduced, promoting increased confidence in the identification of "correct" and "incorrect" technique. A specific goal therefore in developing this tool further would be to increase the sample size on which the "gold standard" kinematic data are based. Given that there were limitations in laboratory, equipment and participant availability throughout the duration of this project, the quantitative tool that has been produced provides a reasonable first attempt at development of such a tool, and provides some interesting conclusions that can be used for continued development.

5.4.6 Conclusions

A minimum of three steps was determined to be appropriate for inclusion in the quantitative assessment tool. Specifically, these steps were the *grand plié in first position*, the *battement tendu derriere,* and the *rise in second position*. These steps were consistent with steps that have been included in previously developed qualitative assessment tools for classical ballet technique. The combination of these three steps enabled the most effective detection of deviations in the kinematic variables that relate to the fundamental principles of classical ballet technique. The *rise* was most effective in detecting differences in the principles of 'placement' (*i.e.* pelvic anterior/posterior tilt and pelvic obliquity) and 'turnout' (*i.e.* hip rotation and ankle rotation), *battements* also picked up differences in 'turnout' (*i.e*. hip rotation), while the *pliés* were sensitive to differences in 'alignment' (*i.e.* thorax anterior/posterior tilt).

A sample quantitative assessment report was presented. Such a report provides individual dancers with specific data (*i.e*. overall z-scores) for all nine kinematic variables assessed in the tool. Summaries of the magnitudes and directions of deviations for "incorrect" variables are provided in graphical format, with stick figures included to assist with data interpretation. Written summaries of elements of "incorrect" technique, and suggestions for their cause and management are also provided. This style of data presentation, together with graphical summaries of changes in technical competency over multiple time points (Figure 5.4) provides individual dancers and their teachers with concise information on their abilities and development in classical ballet technique. Inter-dancer and inter-group comparisons are also facilitated by the quantitative assessment tool (Figure 5.3), thereby allowing individual dancer assessment and ranking, as well as comparison of technical competency between groups or classes.

The development of this quantitative tool has come as the culmination of multiple phases of analysis presented in this research thesis. Four fundamental theoretical principles of classical ballet technique were identified through review of relevant dance literature. The relevance of these theoretical principles with respect to current highly skilled practical execution of classical ballet technique was then investigated. The accuracy with which classical ballet teachers are able to qualitatively identify "correct" and "incorrect" technique was then studied. The results of this analysis indicated that development of an objective quantitative assessment tool for classical ballet technique was in fact necessary. The implications on classical ballet teaching practice of the findings from each phase of this research project will be discussed in the next and final chapter.

CHAPTER 6

CONCLUSIONS AND IMPLICATIONS FOR TEACHING PRACTICE

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6.1 Specific Conclusions and Implications

Following a comprehensive review of the literature, results of linked projects have been presented in this thesis. Each project is themed around classical ballet technique, with the aim of contributing new knowledge to the biomechanics of classical ballet technique and to dance teaching practice. This thesis has presented the first biomechanical analysis of classical ballet technique with respect to is fundamental principles assessed across multiple steps. The thesis has also presented original work investigating the accuracy of qualitative analysis skills in assessing classical ballet technique. Development of a unique protocol for quantitative screening of classical ballet technique was also discussed. This section will summarise the conclusions for each project with respect to their implications for ballet teaching practice.

6.1.1 Comparison of Theoretical and Practical Execution of Classical Ballet Technique

Classical ballet teachers typically instruct their students by providing verbal cues to describe or correct movements. Ideally, the information given should be accurate with respect to anatomical and biomechanical knowledge and principles, as well as aligning with classical ballet teaching objectives. These cues should have a biomechanical basis that is logical, and include instructions or descriptions that are anatomically and physically possible. Given that the fundamental principles of classical ballet technique are deeply rooted in historical tradition, it is not surprising that much about classical ballet teaching practice has also been passed down through many generations in a non-scientific form. Although the longevity and frequency of use of certain instructional theories and cues may imply they have validity as useful teaching aids, the question posed was whether or not they would in fact stand up to scientific scrutiny. The aim of the first project was to examine quantitatively the long-held beliefs about “correct” classical ballet technique through comparison of theoretical information with kinematic data measured on professional and non-professional dancers.

In relation to the four fundamental principles of classical ballet technique identified in the dance literature, it is evident that for the principles of ‘extension’ and ‘turnout’, the practical data are in close agreement with the theoretical concepts. In contrast however, some discrepancies were observed for the principles of ‘alignment’ and ‘placement’. The findings for each fundamental principle and associated implications for ballet teaching practice will be outlined in the following sections.

6.1.1.1 Alignment

It was found that ballet dancers typically hold their thorax in a position of posterior thoracic tilt, rather than the vertical position typically described in the literature. They achieve the desired ‘grand’ or ‘regal’ appearance by taking their thorax beyond the posture typically exhibited by most people during everyday life. In considering the ramifications of this finding on current teaching practice, care should be taken in translating these biomechanical results into useful verbal cues or instructions. For example, in helping students achieve the aesthetic of ‘grand manners’ it may not in fact be advisable to instruct them to tilt their thorax posteriorly (backward), as such a cue could invite increased lumbar extension and posterior shift of the centre of gravity (*i.e.* body weight). A more useful cue that still aligns with the practical data could be to “slightly lift the sternum (breast bone) up”, as this may have the effect of subtly altering the orientation of the thorax, thereby achieving the desired ‘alignment’ and aesthetic without introducing other functional problems.

Also in relation to ‘alignment’ was the finding that when functionally necessary professional ballet dancers “bend the rules” of the theoretical principle and utilise an increased range of anterior/posterior thoracic movement. Specifically, this discrepancy between theory and practice was observed for the jumps (*i.e. sautés* and *temps levés*). From a biomechanical perspective, it is a natural and instinctive movement response to move the trunk forward in preparing for a jump, as this facilitates increased hip extensor power during push-off. The long-held belief that in performing jumps correctly the dancer must “mask the effort by keeping the body erect” (Royal Academy of Dance, 1997, p79), has informed much of the teaching practice to date. However the instruction to aim for maximum elevation off the floor while simultaneously using limited trunk flexion is functionally contradictory and therefore extremely challenging. If dance teachers had increased awareness of how some biomechanical principles may introduce certain challenges to achieving aesthetic aims then they could potentially provide better assistance to their students in achieving a satisfactory compromise between functional and aesthetic requirements.

6.1.1.2 Placement

In terms of standard clinical and biomechanical conventions, professional and non-professional dancers hold their pelvis in a position of at least 10° anterior tilt during execution of most ballet steps. This pelvic position is not dissimilar to that used during normal human gait. Thus, the "centred" or "neutral" pelvic placement often referred to in the theoretical dance literature is not demonstrated practically by ballet dancers, and is therefore not an accurate description in the biomechanical sense. Since, in executing classical ballet technique correct 'placement' is not achieved by altering the pelvis from its usual position for daily activities, cues that place considerable emphasis on pelvic anterior/posterior tilt may in fact be not always necessary. Instructions should be limited to cues that focus on optimal usage of the musculature around the pelvis, rather than pelvic orientation. In instances where individual students do have excessive anterior pelvic tilt or lumbar lordosis attention should be drawn to pelvic sagittal placement. However, if the dancer's pelvic tilt is within a normal range then over emphasising sagittal plane placement may result in excess "tucking" of the pelvis (*i.e.* movement towards posterior tilt) beyond a functionally efficient position.

The finding that, on average, from start to peak of the steps professional dancers demonstrate a smaller range of pelvic sagittal plane motion than non-professionals, supports the theoretical idea of "minimal displacement of the pelvis", and indicates that more experienced dancers are better able to control or isolate their sagittal pelvic motion in relation to the motion of their lower limb. Instruction to stabilise the pelvis and minimise its anterior/posterior range of motion does therefore appear to be appropriate. Specific training of the correct use of the abdominals, gluteals, and hamstrings would help achieve this aim of minimal pelvic displacement.

In contrast to the finding for sagittal plane pelvic motion, the coronal and transverse plane motion demonstrated by professional dancers is not consistent with the theoretical literature. Professional and non-professional dancers exhibit raised pelvic obliquity on the working side when performing a 45° leg elevation to the front, and interestingly, despite the theoretical ideal that “the hips and shoulders must always face the same plane” (Lawson, 1979, p34), the professionals display greater pelvic-thoracic rotation during execution of this step than the non-professionals. More pelvic-thoracic rotation than would be theoretically expected was also observed for the *battement tendu derriere*. For this movement, close to 10° of transverse pelvic rotation was exhibited by both groups of dancers. This finding indicates therefore that even for single leg extensions where the ‘working leg’ remains in contact with the floor (*i.e. battement tendu*) there is concurrent motion of the pelvis and thigh during even the most basic *battement* movement. Ballet dancers are commonly taught to "keep the pelvis square" (*i.e*. the pelvis should not move with lower extremity movements) and this cue is often strongly emphasised when performing leg movements behind the body. The current finding of 10° transverse pelvic-thoracic rotation for highly skilled professional ballet dancers even for an *a terre* (*i.e.* floor bound) posterior leg movement, adds scientific rigour to the suggestion that the pelvis does in fact “open” during posteriorly directed leg movements in classical ballet. Given that the *arabesque* (*i.e.* extension of one leg behind the body) is a signature pose or position of the classical ballet repertoire, these findings have significant implications for classical ballet instruction, in that the "square pelvis" cue has been shown to be inaccurate with respect to transverse plane motion and is therefore not a useful instruction.

6.1.1.3 Turnout

Professional ballet dancers perform classical ballet steps with close to 5° more external transverse hip rotation than non-professional dancers. This finding is in agreement with the theoretical ideal of maximal ‘turnout’, in that highly skilled dancers are able to demonstrate this principle to a greater extent than less skilled dancers. However, the actual values of external hip rotation demonstrated by professional dancers in this study (*i.e.* highest mean value of 40°) are below the ideal values of 60°-90° presented in the literature. Thus, it appears that the theoretical ideal may be beyond the limitations of many highly skilled professional ballet dancers. In relation to external ankle rotation, again, the professional dancers demonstrate increased external rotation compared to non-professionals, indicating that transverse rotation at the ankle joint does in fact contribute to the overall 'turnout' of the lower limb.

The conclusions for the principle of 'turnout' have implications with respect to dancer safety in classical ballet instruction. It appears that the theoretical data for hip external rotation in classical ballet are based primarily on passive static measurement methods (Champion and Chatfield, 2008). While these data may in fact be accurate for this measurement condition, their relevance and use as a benchmark for the level of active external hip rotation that can be achieved during dynamic dance movements is questionable. The theoretical values typically presented in the dance literature may in fact give ballet teachers misguided expectations as to what is an appropriate degree of active external hip rotation for dancers to achieve. In striving to create the desired aesthetic, dancers often force their hip rotation beyond the limits of their personal safety, sometimes resulting in injury (Negus *et al.*, 2005). While 'turnout' is undeniably a crucial requirement for execution of correct classical ballet technique, the 20° difference between active practical and passive theoretical hip rotation revealed in the current study, indicate that dance teachers should be discouraged from habitually repeating cues relating to hip turnout, without careful consideration of the physical limitations of the individuals they are addressing.

The "heel forward" or slightly "winged" position of the foot and ankle, particularly for a fully extended 'working' leg, is encouraged in classical ballet instruction as it creates an appealing aesthetic. The finding that the degree of ankle external rotation that contributes to this position is influenced by concurrent plantarflexion or dorsiflexion has implications for classical ballet instruction. Providing dance teachers with more detailed information about the mechanics of the ankle joint complex and the interplay of simultaneous movement across multiple planes, may assist teachers in understanding why it is that for some dancers the "heel forward" position with simultaneous plantarflexion is particularly difficult to achieve. Increased information and understanding in this area could therefore help teachers deliver appropriate exercises to encourage safe and aesthetically pleasing ankle rotation.

6.1.1.4 *Extension*

Professional and non-professional dancers demonstrate knee hyperextension when required to perform maximum knee extension. However, professional dancers exhibit a significantly greater degree of knee hyperextension than non-professionals. The position achieved by the professionals (up to 13° hyperextension) is extreme in relation to the knee positions typically used during everyday life, and is in agreement with the theoretical principle of maximum 'extension'. While this extreme knee hyperextension may reflect the desired theoretical aesthetic described in the literature, care should be taken with respect to how this position is dealt with from a practical teaching perspective. In the most severe cases, constant knee hyperextension can lead to damage to the anterior cruciate ligament (ACL), due to strain of the postero-lateral bundle of the ligament (Fornalski *et al.*, 2008; Vogel, 2007). While some knee hyperextension is considered desirable in achieving the aesthetics of classical ballet, there are differing opinions, with respect to knee joint safety, about the degree of knee hyperextension that is considered appropriate. Some instructors and clinical therapists believe that any degree of weight-bearing knee hyperextension places undue stress across the knee joint and is therefore potentially injurious, while others feel some controlled knee hyperextension is acceptable (Grieg, 1994). The knee extension data obtained for the steps analysed in the current study indicate that the highest measures for knee hyperextension generally were obtained for both groups when the legs were in a weight-bearing *second position* (*i.e.* feet separated), and specifically, at the start of the *rise in second position* and the *grand plié in second position*. This finding indicates that the body position adopted can determine the resulting degree of knee hyperextension.

From a biomechanical perspective, the increased knee hyperextension occurring in weight-bearing *second position* occurs as result of the separation of the feet. That is, an increased knee extensor torque/moment is placed across the knee joint due to the increased horizontal displacement of the body's line of gravity from the knee flexion/extension axis. If not appropriately counteracted with the necessary knee flexor muscle activation (*i.e.* hamstrings and gracilis), then increased uncontrolled knee extension results, with increased stress being placed on knee joint ligaments. To prevent knee joint injury, it is crucial therefore that ballet teachers have a thorough understanding of the implications of the positions of the legs on the stresses invoked at the knee. Given that knee hyperextension in classical ballet can be visually appealing, dancers with natural knee hyperextension are typically selected into vocational training programs. In training such dancers it is important therefore that teachers develop the skills and knowledge to effectively instruct their students in the correct use of the specific musculature (*i.e.* hamstrings and gracilis) that can protect the knee from potentially unsafe weight-bearing hyperextension.

Professional ballet dancers also demonstrate increased ankle plantarflexion compared to non-professionals, a finding that is also consistent with the theoretical concept that extreme elongation ('extension') of the lower limb is a characteristic of elite classical ballet technique. As is likely the case for knee hyperextension, the degree of ankle plantarflexion and the ankle shape achieved during maximal ankle extension is largely determined by genetics. Therefore, although some increased plantarflexion can be achieved to an extent during the earlier years of ballet training, there are varying degrees of structural limitation at the ankle joint for different individuals. Such limitations must be duly acknowledged and respected by dance teachers in the provision of safe dance training, and less "*pointed*" feet should not be forced beyond the limits of safety. At the other extreme, the highly "arched" or flexible ankle joint often seen in professional dancers, and suggested by the current data, introduces significant safety issues with regard to dancing *en pointe.* Although aesthetically pleasing, this type of foot can initially be very unstable *en pointe.* It is very important therefore that teachers are fully aware of the safety issues associated with this type of ankle joint, and equip their students with the necessary knowledge and skills to gain adequate strength and control across their feet and ankles.

In summarising the conclusions and associated implications of the first project, the key feature that comes forth is the importance for classical ballet teachers to develop some understanding of the basic biomechanical concepts that relate to the safety and efficacy of dance-related movement. Knowledge of concepts such as joint forces, torques/moments and powers, and how these are influenced by relative positions of body segments, joint axes, and the body's centre of gravity would certainly enhance a teacher's ability to assist their students acquire safe and efficient technique. Although there has been an increased awareness of safe dance practice over recent decades (*e.g.* Ausdance Safe Dance Report 1

(Geeves, 1990); Ausdance Safe Dance Report 2 (Geeves, 1997); Ausdance Safe Dance Report 3 (Crookshank, 1999); The Dancer Wellness Project 2002-2012 (http://www.dancerwellnessproject.com), similar focus has not been given to instruction of biomechanically efficient dance practice. To date it appears that basic biomechanical knowledge is not deemed by the dance community to be an integral component of skilful dance instruction. However, it is suggested by the author that such knowledge, communicated to dancers in an appropriate and accessible style, could not only contribute to injury prevention, but also to highly efficient motor skill acquisition.

In addition, the dissemination of the findings of the literature review on classical ballet technique to classical ballet teachers is also suggested by the author to have important implications for classical ballet instruction. It would be beneficial to highlight that the crucial elements of correct classical ballet can in fact be simplified into a few fundamental principles. Thinking about the technique and describing it in terms of these few key elements may reduce complexity and confusion in the teaching cues typically employed, thereby promoting increased student understanding of the instructions provided and of the physical goals they are aiming to achieve.

6.1.2 Qualitative Analysis of Classical Ballet Technique

Movement instructors provide their students with feedback on their performance by informing them how their movement response compares to the ideal template or prototype for their particular discipline. The efficacy of this feedback depends largely on the instructor's ability to "identify the aspects of the response which are preventing the learner from attaining the skill objective" (Armstrong and Hoffman, 1979, p318). It follows then that instructors who lack proficiency in identifying correct or incorrect technique are unable to access critical information on which to base constructive feedback. The value of their feedback, and consequent capacity for skill acquisition by their students, would therefore be greatly diminished. This project aimed to assess the accuracy with which ballet teachers are able to identify correct and incorrect classical ballet technique, and the effect of teaching experience on this capacity.

Comparison of the ballet teachers' qualitative responses with quantitative kinematic data obtained from 3D motion analysis, revealed that accuracy of qualitative analysis of classical ballet technique improved significantly between 1 and 9 years experience, but plateaued beyond 10 years experience. Improvement in accuracy from 1 to 9 years experience was due to increasing sensitivity to detection of “incorrect” ballet technique. It has been argued (Osborne and Gordon, 1972) that it is far more important that incorrect movements, as opposed to correct movements, be identified accurately so that faulty movements can be remedied, thereby facilitating efficient progression towards successful acquisition of a skill. The current study therefore provides encouraging data to indicate that with increasing experience ballet teachers become more discriminating in their judgement of what constitutes incorrect technique, and therefore do in fact develop increasing skill in an element of qualitative analysis that is highly important for effective teaching practice.

A noticeable trend was for the more experienced teachers to rate correct technique as “incorrect” more so than less experienced teachers. That is, with increasing experience teachers demonstrated decreased specificity for identification of “correct” technique. Although identification of “incorrect” technique appears to be given more value in teaching practice (Osborne and Gordon, 1972), it is also important to recognise the importance of accurate identification of “correct” technique. Failure by a movement instructor to recognise that a particular technical element is actually correct and to instead rate it as incorrect will place unnecessary attention on a body region or movement quality that does not need to be corrected. The adverse outcome of such misdiagnosis is that perfectly adequate movement patterns may be unnecessarily altered and/or the student’s focus and efforts distracted from other elements that may actually be incorrect and therefore in need of attention. Moreover, from a psychological perspective, the recognition and positive reinforcement of correct technique may provide encouragement, increased motivation and confidence for students. Rist (2001) states that a useful feedback tool is the “specific praise method”, in which the “dancer is praised for effort and told specifically what was good about it”. Praise given in this way actually reinforces the change in technique, thereby anchoring the achievement (Rist, 2001, p431). Results of the current study however, suggest that perhaps more experienced teachers are too “picky” or are reluctant to acknowledge correct technique. Failure by experienced teachers to recognise correct technique has negative implications for teaching practice in that valuable positive feedback may be constantly withheld from students.

Despite increasing accuracy of qualitative analysis with increasing teaching experience, it should be highlighted that even teachers with at least 10 years experience only achieved a mean overall percentage accuracy score of 65%, a result which is only 15% better than that produced by chance alone. It therefore took nearly 10 years of experience for ballet teachers to acquire only a relatively low level of observational accuracy. Even more concerning is the finding that beyond 10 years of experience the accuracy of qualitative analysis did not significantly improve. Ericsson and colleagues (Ericsson and Charness, 1994; Ericsson and Lehmann, 1996) argued that expertise is not attained as an automatic consequence of experience, but rather, through structured and effortful adaptation affected by training. They therefore suggested that specific training methods should be developed that facilitate the development of the critical domain-specific skills that lead to expertise. In addition, it was stated (Ericsson and Charness, 1994) that in order for improvement to occur, regular training activities should offer accurate, preferably immediate, feedback or opportunities for corrected repetitions. In line with this argument, the results of the current study support the suggestion for implementation of increased training in qualitative analysis of highly skilled dance movement. The fact that there was no significant effect of participation in a teacher training program on the accuracy of qualitative analysis, suggests that to date training in qualitative analysis is not a major component of the curricula in existing teacher training programs. If implemented, such training should consist of goal directed activities with specific feedback, as this will lead to improved acquisition of qualitative analysis skill compared to non-planned non goal directed activities.

The fact that employment as a professional classical ballet dancer did not significantly affect the accuracy of qualitative analysis of classical ballet technique also has substantial implications for teaching practice. It appears to be an accepted belief that a highly accomplished dancer will automatically have the skills required to be a highly effective teacher. However, the results of the current study suggest that, with respect to identification of “correct” and “incorrect” technique, this is not in fact the case. Attaining an expert level of practical skill in classical ballet is not necessarily accompanied by a corresponding level of skill in qualitative analysis relative to teachers who did not perform professionally. Therefore dancers transitioning from the position of elite dancer to dance teacher, may not immediately possess all of the skills required for expert movement instruction. It should be recognised that sufficient time, training and experience is required to develop these important skills, and retiring professional dancers should therefore be encouraged to complete teacher training programs incorporating goal-directed tuition in qualitative analysis.

The implications of the results of this study on classical ballet teaching practice are that all aspiring ballet teachers, whether coming from a professional performance background or not, would benefit from participation in training programs designed specifically to improve qualitative analysis of ballet technique. Teacher training programs appear to be currently lacking in such curricula, and the dance teaching profession will benefit greatly from attention being turned towards this area of teaching practice. The implementation of such programs will increase the rate of improvement in qualitative analysis, and on-going education in this area will ensure that accuracy of observation does not plateau beyond a certain level of experience. Although accurate identification of "incorrect" technique is critical, the importance for the student of identification and reinforcement of "correct" technique should also be duly acknowledged as an essential component of effective feedback.

6.1.3 Development of a Quantitative Assessment Tool for Classical Ballet Technique

In response to the relatively low accuracy of qualitative analysis demonstrated by professional ballet teachers, a quantitative assessment tool based on 3D motion analysis data was developed for the evaluation of classical ballet technique. A specific aim in developing this tool was to determine the minimum number of ballet steps required to enable effective detection of deviations in the kinematic variables relating to the four fundamental principles of classical ballet technique. The need for determining the minimum number of steps was driven by recognition of the potential financial and time costs of 3D motion analysis. It was determined that a minimum of three steps were required, and in fact the use of only three appropriate steps produced an assessment tool that was more sensitive to deviations in the relevant kinematic variables than a tool containing 14 steps. The three steps that were identified as being most effective in detecting deviations between professional and non-professional dancers, were the *grand plié in first position*, the *battement tendu derriere*, and the *rise in second position*.

Given the inaccuracies in qualitative analysis of classical ballet technique identified in the previous project, development of a quantitative assessment tool designed specifically for classical ballet technique is a potentially valuable contribution to the dance teaching profession. The tool provides a mechanism to obtain systematic, objective and concise information on the technical competencies of ballet dancers, as well as the teaching abilities of dance instructors. Inter-dancer comparisons could provide a means for ranking and assessing dancers within a given group, while inter-group comparisons would enable evaluation of the effects of different teachers or teaching styles on different groups, or the same groups over multiple time points. For example, specific training programs or techniques could be implemented for defined periods of time and the quantitative assessment tool could provide an objective and accurate means to assess their outcome or efficacy. In addition, the tool could also enable systematic evaluation of the progress, or lack thereof, of individual dancers over time.

Other potential benefits of the quantitative assessment tool to classical ballet teaching practice include its use in the evaluation of the accuracy of qualitative analysis. Similar to the process conducted in the second project, qualitative responses provided by teachers could be compared to quantitative data obtained from the assessment tool. Teachers participating in this process would receive feedback on the accuracy of their observations, and specific areas for which their accuracy is poor, and thus in need of attention. Given the importance of structured learning in skill acquisition (Ericsson *et al.*, 1993), this tool could therefore be a valuable source of feedback and as such a very useful resource for teacher training. The results of subsequent re-evaluation of accuracy of qualitative analysis after implementation of training programs designed to improve observation skills, could also have important implications on classical ballet teaching. Such a process could provide valuable information for the development and evaluation of dance teacher training programs.

In practice, if each dancer performed three steps, a cohort of 20 dancers could be assessed in a motion analysis laboratory in one to two days. The subsequent data analysis and reporting would be relatively rapid, an additional two days, if a modern motion analysis system and standard automated protocol, as suggested by the author, were used.

It is acknowledged that the equipment and technical expertise required to perform 3D quantitative motion analysis is currently not readily available to most dance institutions and instructors. However, the information that has been obtained through development of this quantitative assessment tool is also applicable to regular qualitative analysis. This study has identified the kinematic variables for which deviations typically occur in the *plié*, *battement*, and *rise* categories of classical ballet. If these same movements were to be included in the qualitative assessment tools regularly used in dance teaching practice, there would be systematically obtained quantitative data to indicate the specific kinematic parameters that teachers should be looking for when observing these steps.

In summary, the quantitative assessment tool developed as part of this research project has many implications for classical ballet instruction. These implications relate to enhancing and evaluating dancer progress and technical development, evaluating and improving teaching practice, and developing curricula for teacher training programs.

6.2 General Conclusions

Four fundamental theoretical principles of classical ballet technique were identified through review of historical and current dance literature, these are:

1) 'Alignment' - maintaining verticality of the torso
2) 'Placement' - minimal displacement of the pelvis from a centred position
3) 'Turnout' - maximum external rotation of lower limbs
4) 'Extension' -maximum elongation of the lower limbs

Through quantitative biomechanical analysis it was concluded that professional dancers demonstrate kinematic variables relating to 'turnout' and 'extension' in agreement with these theoretical principles, however some deviations between practice and theory were observed in the areas of 'alignment' and 'placement'. The deviations observed were considered to be due primarily to functional necessity. That is, although classical ballet technique is based on distinct aesthetic ideals, it appears that in some instances it is necessary to compromise on these aesthetic ideals in order to achieve the functional biomechanical requirements of particular movements or steps. It is suggested therefore that increased understanding by ballet teachers of basic biomechanical and anatomical principles and how they influence human movement function will greatly enhance teaching practice. Increased awareness of the ways in which an appropriate balance between the aesthetic ideals and functional requirements of the technique can be achieved will facilitate efficient skill acquisition and safe practice in classical ballet instruction. Additionally, attainment of more detailed biomechanical understanding by dance educators, would lead to a shift in the manner in which the principles of classical ballet technique are typically presented and discussed.

The accuracy with which classical ballet teachers are able to identify "correct" and "incorrect" ballet technique in relation to "gold standard" practical kinematic data was also investigated. A positive relationship between years of professional teaching experience and accuracy of qualitative analysis was demonstrated from 1 to 9 years of experience, however this plateaued after 10 years experience. The improvement in accuracy with increasing experience was due to increased sensitivity to the detection of "incorrect" technique. Despite this improvement, even the most experienced teachers, some with as much as 20 and 30 years experience, only achieved moderate accuracy. Perhaps it is due to a deficiency in understanding of basic biomechanical concepts that ballet teachers only demonstrate moderate accuracy of qualitative analysis.

It has been stated (Wilson, 2009, p11) that "dance teachers train students to develop both artistry and skill, relying on their innate understanding of the body moving through space". However, in considering the conclusions reached from the projects, it appears that teachers' "innate understanding" of movement may in fact not be enough to facilitate expert teaching practice. Moreover, it has been argued that expertise is not necessarily attained as an automatic consequence of experience, but, rather, through structured and effortful adaptation affected by training (Ericsson and Charness, 1994). It is proposed therefore, that dance teaching practice would benefit greatly from the development of training programs containing carefully constructed curricula that includes basic biomechanics and principles of qualitative analysis. It is suggested that well planned, goal-directed training in these areas would equip teachers with more information with which to conduct accurate and efficient qualitative analysis, which would in turn promote effective feedback and successful skill acquisition.

A quantitative tool was developed to provide an objective and systematic means for analysis of classical ballet technique. Using kinematic data from professional dancers as a reference for "correct" technique, a minimum of three steps (*i.e. plié in first position; battements tendu derriere; rise in second position*) were identified as being adequate for the detection of deviations in kinematic variables relating to 'alignment', 'placement' 'turnout', and 'extension'. This tool could potentially be used to evaluate the progress and technical development of individual dancers, to evaluating teaching practice, and to assist with developing curricula for teacher training programs.

6.3 Future Directions

In completing each project, a number of areas for future research were identified. Firstly, as already mentioned in previous chapters, it would be beneficial to increase the number of professional ballet dancers on whom the benchmark or reference data for “correct” technique are based. This process would add further evidence to support the validity of the techniques used to assess accuracy of qualitative analysis, and also to the validity of the data obtained from the quantitative assessment tool. In addition, it would be interesting to expand the geographical location from which professional dancers are recruited. Ballet dancers from different countries and regions of the world are known within the international dance community to have distinct movement characteristics or attributes developed within specific training systems. Compilation and comparison of kinematic data from professional ballet dancers trained within different regional systems or syllabi, would enable identification of the universal kinematic features as well as highlighting regional differences.

Having determined that the implementation of training programs in basic biomechanics and qualitative analysis would be beneficial for ballet teachers, it would be interesting to assess the efficacy of such programs once established and delivered. This would involve using techniques similar to those described in Chapter 4 to obtain baseline data for the accuracy of qualitative analysis for a sample of teachers, and then performing repeat assessments at one or more subsequent time points. Comparison of data from a control group who did not take part in the training program could highlight any specific effects of the program.

Examination of the visual search strategies used by ballet teachers when observing ballet technique could also provide some useful data. Results from Chapter 4 of this thesis showed that when asked to select a body region in need of correction, greater consistency in responses was obtained amongst more experienced ballet teachers. Specifically, it was the pelvis that was most frequently selected by the more experienced teachers. Visual search behaviour is typically examined using an eye movement registration system. These systems, which can be floor- or head-mounted, record eye movements as well as the interspersed visual fixations as they perform the task. The duration of each fixation is presumed to represent the amount of cognitive processing, whereas the point of gaze is assumed to indicate areas of interest (Williams, 2002, p169). Investigation of visual search strategies would therefore reveal which body regions experienced and non-experienced teachers observe the most, and what are the durations and frequencies of these fixations with respect to body regions chosen for correction. Such analyses could provide valuable information to enhance teacher training.

Finally, if logistically possible, pilot testing of the regular use of the quantitative assessment tool in a dance education institution would enable evaluation of its efficacy and feasibility. To assess the feasibility and practicality of the tool it would be necessary to monitor the time required for data collection, data processing and report production. Methods for assessing and maintaining data quality would also need to be established. In addition, a survey of the user-friendliness or ease of understanding of the data presented in the assessment tool report would also assist in enhancing the tool further. Once the procedures and protocols associated with the tool are fine-tuned, its efficacy in systematically measuring the progression of individual dancers or efficacy of individual teachers or training programs could be assessed.

In conclusion, there is much scope for future research of many important factors that can enhance teaching practice in classical ballet. The current project has provided an important and significant contribution towards these future scientific endeavours.

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APPENDICES

APPENDICES

Appendix A: Ethics Approval for Chapter 3 – Comparison of Theoretical and Practical Execution of Classical Ballet Technique

COPY

THE UNIVERSITY OF
NEW SOUTH WALES

HUMAN RESEARCH ETHICS

25 September 2009

Human Research Ethics Advisory Panel 'H'
Accepted Application

Ms Rachel Ward
School of Risk and Safety Sciences
UNSW

RE: **Biomechanical Investigation of the Accuracy of Visual Observation and Efficacy of Verbal Instruction in Classical Ballet Teaching.**
Part 1: Comparison of theoretical and practical execution of "Correct" classical ballet technique.

Reference Number: **08/2009/48**
Investigator/s: **Ms Rachel Ward, Dr John Mullins**
Supervisor: **Professor Andrew McIntosh**

At its meeting on 14 September 2009, the Human Research Ethics Advisory Panel 'H' has recommended to your Head of School and the Human Research Ethics Committee that this project is of minimal ethical impact.

Your application has been given Approval for a 12 month period ending 14 September 2010. You may proceed with your research.

A/Professor Arthur Ramer
Convener,
Human Research Ethics Advisory Panel 'H'

A/Professor Roger Read
Acting Head of School
School of Risk and Safety Sciences

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Appendix B: Information and Consent Form for Non-professional Ballet Dancers

THE UNIVERSITY OF NEW SOUTH WALES

School of Risk and Safety Sciences
School of English, Media & Performing Arts
Approval Number: 08/2009/48

BIOMECHANICAL INVESTIGATION OF THE ACCURACY OF VISUAL OBSERVATION AND EFFICACY OF VERBAL INSTRUCTION IN CLASSICAL BALLET TEACHING

Information for Participants
Group 1: Non-professional Ballet Dancers

You (the research participant) are invited to participate in a study investigating the fundamental biomechanical characteristics of classical ballet technique, and the characteristics of effective classical ballet teaching. We (the investigators) hope to determine:

1. if professional/elite classical ballet dancers execute classical ballet technique more closely to the theoretical principles outlined in the dance literature than amateur/non-professional ballet dancers do.
2. the accuracy and efficacy with which ballet teachers visually observe and verbally instruct students of classical ballet.

This study is being conducted by the School of Risk and Safety Sciences and the School of English, Media & Performing Arts at the University of New South Wales (UNSW). The research team will firstly use three-dimensional motion analysis data to compare the movement patterns of amateur/non-professional ballet dancers with professional ballet dancers performing standard classical ballet steps. The study will then use video images and motion analysis data of participating dancers to examine the accuracy with which classical ballet teachers can visually observe the movement patterns executed by the dancers.

You were selected as a possible participant in Group 1 of this study because you are female; are over 18 years of age; have received training in classical ballet; have passed at least a minimum of the Royal Academy of Dancing Intermediate (formerly known as "Elementary") graded examination, or another ballet syllabus examination of equivalent level; and you have never been employed as a professional dancer in a professional ballet company.

If you decide to participate, you will be required to visit the Biomechanics Laboratory at the School of Risk and Safety Sciences at the University of New South Wales Kensington Campus to take part in a three-dimensional full-body computerised motion analysis session. During the motion analysis session, your date of birth, height, weight, body proportions, and passive joint ranges of motion will be measured and recorded. You will then have at least 40 spherical retro-reflective markers attached to your body and will be asked to perform a selection of standard classical ballet steps. Video images as well as three-dimensional computer images will be taken of you as you execute each dance step. For the motion analysis session you will be required to wear only tight short bike-pants and a crop-top, it will be necessary for your abdominal area, legs and arms to be exposed. You will also be required to complete a questionnaire outlining your dance training and performance history, study background, and dance injury history. The entire analysis session will take 2 to 3 hours. All participating dancers will be given a pair of Bloch foot thongs to wear during the motion analysis session, and keep thereafter.

Approval No: 08/2009/48 *Biomechanics of Ballet Technique* Version No: 1.1, Date: 20 Aug 09 Page 1 of 3

Appendix B continued:

THE UNIVERSITY OF
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Although the ballet steps you will be asked to perform will only be of an elementary/intermediate level and no different to the movements regularly performed in standard classical ballet classes, there is still a remote possibility that you may sustain a musculoskeletal injury. Please note that you will not be asked to perform any movements that cause you pain or discomfort.

Any information that is obtained in connection with this study and that can be identified with you will remain confidential and will be disclosed only with your permission, except as required by law. If you give us your permission by signing this document, we plan to use the video images of you for the second part of this research project. The second part of the study will involve showing the video images of you to a number of ballet teachers who will be recruited as subjects for the study. The dance teachers will watch the video images of you performing the ballet steps and will respond to questions related to their perception of your execution of the dance steps. All study participants that view video data of you will be required to sign a confidentiality agreement stating that they will treat any information they see related to you or your dance technique with the strictest of confidence. Your name will not be displayed with or used in reference to your video images. Your body proportion, height, weight and three-dimensional motion analysis data will be used for analysis and presentation in a doctoral thesis, it will also be published in local and international journal articles and conference presentations. In any publication, information will be provided in such a way that you cannot be identified.

Complaints may be directed to the Ethics Secretariat, The University of New South Wales, SYDNEY 2052 AUSTRALIA (phone 9385 4234, fax 9385 6648, email ethics.sec@unsw.edu.au). Any complaint you make will be investigated promptly and you will be informed about the outcome.

Feedback regarding the study's findings may be made available through the School of Risk and Safety Sciences' website at www.srss.unsw.edu.au, and through dance and human movement-related publications, including journal articles, magazines, newsletters, and conference presentations and proceedings.

Your decision whether or not to participate will not prejudice your future relations with the University of New South Wales. If you decide to participate, you are free to withdraw your consent and to discontinue participation at any time without prejudice.

If you have any questions, please feel free to ask us. If you have any additional questions later, Rachel Ward (Phone: 0419 273 454; Email: rachel.ward@unsw.edu.au) will be happy to answer them.

You will be given a copy of this form to keep.

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Appendix B continued:

THE UNIVERSITY OF NEW SOUTH WALES

School of Risk and Safety Sciences
School of English, Media & Performing Arts
Approval Number: 08/2009/48

BIOMECHANICAL INVESTIGATION OF THE ACCURACY OF VISUAL OBSERVATION AND EFFICACY OF VERBAL INSTRUCTION IN CLASSICAL BALLET TEACHING

PARTICIPANT CONSENT FORM

I,

....

[Please PRINT full name]

have read and understood the Information for Participants on the above named research study.

I have been made aware of the procedures involved in the study, including any known or expected inconvenience, risk, discomfort or potential side effects and of their implications as far as they are currently known by the researchers.

I freely choose to participate in this study and understand that I can withdraw at any time.

I also understand that the research study is strictly confidential.

I hereby agree to participate in this research study.

....

Signature of Participant

....

Date

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Appendix C: Information and Consent Form for Professional Ballet Dancers

THE UNIVERSITY OF
NEW SOUTH WALES

School of Risk and Safety Sciences
School of English, Media & Performing Arts
Approval Number: 08/2009/48

BIOMECHANICAL INVESTIGATION OF THE ACCURACY OF VISUAL OBSERVATION AND EFFICACY OF VERBAL INSTRUCTION IN CLASSICAL BALLET TEACHING

Information for Participants
Group 2: Professional Ballet Dancers

You (the research participant) are invited to participate in a study investigating the fundamental biomechanical characteristics of classical ballet technique, and the characteristics of effective classical ballet teaching. We (the investigators) hope to determine:

1. if professional/elite classical ballet dancers execute classical ballet technique more closely to the theoretical principles outlined in the dance literature than amateur/non-professional ballet dancers do.
2. the accuracy and efficacy with which ballet teachers visually observe and verbally instruct students of classical ballet.

This study is being conducted by the School of Risk and Safety Sciences and the School of English, Media & Performing Arts at the University of New South Wales (UNSW). The research team will firstly use three-dimensional motion analysis data to compare the movement patterns of amateur/non-professional ballet dancers with professional ballet dancers performing standard classical ballet steps. The study will then use video images and motion analysis data of participating dancers to examine the accuracy with which classical ballet teachers can visually observe the movement patterns executed by the dancers.

You were selected as a possible participant in Group 2 of this study because you are female; are over 18 years of age; and have been employed as a dancer in a professional ballet company within the past 6 months.

If you decide to participate, you will be required to visit the Biomechanics Laboratory at the School of Risk and Safety Sciences at the University of New South Wales Kensington Campus to take part in a three-dimensional full-body computerised motion analysis session. During the motion analysis session, your date of birth, height, weight, body proportions, and passive joint ranges of motion will be measured and recorded. You will then have at least 40 spherical retro-reflective markers attached to your body and will be asked to perform a selection of standard classical ballet steps. Video images as well as three-dimensional computer images will be taken of you as you execute each dance step. For the motion analysis session you will be required to wear only tight short bike-pants and a crop-top, it will be necessary for your abdominal area, legs and arms to be exposed. You will also be required to complete a questionnaire outlining your dance training and performance history, study background, and dance injury history. The entire analysis session will take 2 to 3 hours.

Although the ballet steps you will be asked to perform will only be of an elementary/intermediate level and no different to the movements regularly performed in standard classical ballet classes, there is still a remote possibility that you may sustain a musculoskeletal injury. Please note that you will not be asked to perform any movements that cause you pain or discomfort.

Appendix C continued:

THE UNIVERSITY OF
NEW SOUTH WALES

Any information that is obtained in connection with this study and that can be identified with you will remain confidential and will be disclosed only with your permission, except as required by law. If you give us your permission by signing this document, we plan to use the video images of you for the second part of this research project. The second part of the study will involve showing the video images of you to a number of ballet teachers who will be recruited as subjects for the study. The dance teachers will watch the video images of you performing the ballet steps and will respond to questions related to their perception of your execution of the dance steps. All study participants that view video data of you will be required to sign a confidentiality agreement stating that they will treat any information they see related to you or your dance technique with the strictest of confidence. Your name will not be displayed with or used in reference to your video images. Your body proportion, height, weight and three-dimensional motion analysis data will be used for analysis and presentation in a doctoral thesis, it will also be published in local and international journal articles and conference presentations. In any publication, information will be provided in such a way that you cannot be identified.

Complaints may be directed to the Ethics Secretariat, The University of New South Wales, SYDNEY 2052 AUSTRALIA (phone 9385 4234, fax 9385 6648, email ethics.sec@unsw.edu.au). Any complaint you make will be investigated promptly and you will be informed out the outcome.

Feedback regarding the study's findings may be made available through the School of Risk and Safety Sciences' website at www.srss.unsw.edu.au, and through dance and human movement-related publications, including journal articles, magazines, newsletters, and conference presentations and proceedings.

Your decision whether or not to participate will not prejudice your future relations with the University of New South Wales. If you decide to participate, you are free to withdraw your consent and to discontinue participation at any time without prejudice.

If you have any questions, please feel free to ask us. If you have any additional questions later, Rachel Ward (Phone: 0419 273 454; Email: rachel.ward@unsw.edu.au) will be happy to answer them.

You will be given a copy of this form to keep.

Approval No: 08/2009/48 *Biomechanics of Ballet Technique* *Version No 1.0, Date: 20 Aug 09* Page 2 of 3

Appendix C continued:

THE UNIVERSITY OF
NEW SOUTH WALES

School of Risk and Safety Sciences
School of English, Media & Performing Arts
Approval Number: 08/2009/48

BIOMECHANICAL INVESTIGATION OF THE ACCURACY OF VISUAL OBSERVATION AND EFFICACY OF VERBAL INSTRUCTION IN CLASSICAL BALLET TEACHING

PARTICIPANT CONSENT FORM

I,

....

[Please PRINT full name]

have read and understood the Information for Participants on the above named research.

I have been made aware of the procedures involved in the study, including any known or expected inconvenience, risk, discomfort or potential side effect and of their implications as far as they are currently known by the researchers.

I freely choose to participate in this study and understand that I can withdraw at any time.

I also understand that the research study is strictly confidential.

I hereby agree to participate in this research study.

....

Signature of Participant

....

Date

Appendix D: Dancer Questionnaire

Dancer ID# ________

THE UNIVERSITY OF NEW SOUTH WALES

School of Risk and Safety Sciences
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Approval Number: 08/2009/48

BIOMECHANICAL INVESTIGATION OF THE ACCURACY OF VISUAL OBSERVATION AND EFFICACY OF VERBAL INSTRUCTION IN CLASSICAL BALLET TEACHING

DANCER QUESTIONNAIRE

Date: ____________________ Date of Birth: ________________ (dd/mm/yy)

Your Dance Training History

1. Have you ever undertaken any formal training in classical ballet? (Yes / No)
2. If yes, at what age did you commence your formal classical ballet training?______ (years)
3. How many years of formal classical ballet training have you had?______ (years)
4. Have you successfully passed any ballet syllabus examinations? (Yes / No)
5. If yes, please specify the name of the ballet syllabus and highest level examination you have passed (e.g. Royal Academy of Dancing (RAD) Intermediate; Cecchetti Advanced 1)

____

____

6. At any time during your ballet training did you undertake full-time classical ballet training? (Yes/No)
7. How long did you undertake full-time classical ballet training?______ (years)
8. Do you still take classical ballet classes (Yes / No)
9. If yes, how many hours of classical ballet classes do you take per week?_________ (hours)
10. If you no longer take classical ballet classes, how long has it been since you stopped taking classical ballet classes?______ (years).

Appendix D continued:

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Dancer ID# ________

11. Do you currently take classes in or perform other styles of dance? (Yes / No)

12. If yes, please circle the other styles of dance that you currently do (circle as many as applicable)

- Jazz
- Tap
- Contemporary
- Ballroom
- Hip Hop
- Street Funk
- Salsa
- Other (please specify) ____________________

13. Which style do you currently spend most of your time doing? (please only circle one)

- Ballet
- Jazz
- Tap
- Contemporary
- Ballroom
- Hip Hop
- Street Funk
- Salsa
- Other (please specify) ____________________

14. How many hours do you spend doing this style of dance per week?______ (hours)

Your Dance Performance History

15. Are you currently working full-time as a classical ballet dancer in a professional classical ballet company (Yes / No)

16. If no, have you ever worked as a professional ballet dancer in a professional classical ballet company (Yes / No)

17. How many years did you work /have you been working as a professional ballet dancer in a professional classical ballet company?______ (years).

18. What was/is the highest rank you have reached in a professional classical ballet company?

____

19. Have you worked as a professional dancer in any other style of dance (e.g. contemporary dance, musical theatre, commercial dance) (Yes / No)

20. Please describe the style of dance you have performed professionally and state the number of years you worked professionally.

____

____

____

Appendix D continued:

THE UNIVERSITY OF NEW SOUTH WALES

Dancer ID# ________

Your Anatomy Background

21. Have you ever undertaken any formal training in human anatomy? (Yes / No)

22. If yes, please list the course/school/ institution/organisation where you took your anatomy training.

____

____

____

____

23. What was the duration of your anatomy course?______ (years), or ______(weeks)

24. Was this course (please circle)
- Full-time
- Part-time

Your Biomechanics Background

25. Have you ever undertaken any formal training in biomechanics of the human body? (Yes / No)

26. If yes, please list the course/school/ institution/organisation where you took your biomechanics training

____

____

____

____

27. What was the duration of your biomechanics course?______ (years), or ______(weeks)

28. Was this course (please circle)
- Full-time
- Part-time

Appendix D continued:

THE UNIVERSITY OF NEW SOUTH WALES

Dancer ID# ________

Your Dance Injury History

29. Are you currently suffering from a dance-related musculoskeletal injury? (Yes / No)

- If yes, please describe the location and nature of the injury (eg. ankle sprain; hamstring strain; Achilles tendonitis)

____

____

____

____

30. Was this injury caused by a one-off incident or is it an over-use injury? (please circle)

- One-off incident
- Over-use injury

31. If one-off incident, please describe how the injury occurred.

____

____

____

____

32. Are you currently taking time off from dancing or have you reduced your dance work load due to this injury? (Yes / No)

33. If yes, how much time have you missed so far?____________________

34. Are you currently receiving treatment or therapy for this injury from a qualified health professional? (Yes / No)

35. If yes, please describe the type of treatment or therapy (e.g. physiotherapy, osteopathic treatment).

____

____

____

____

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Appendix D continued:

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Dancer ID# ________

36. Have you experienced any dance-related injuries in the past 6 months for which you were required to take time off from dancing or to reduce your dance work load? (Yes / No)

    - If yes, please describe the location and nature of the injury (eg. ankle sprain; hamstring strain; Achilles tendonitis)

____

____

____

____

37. Was this injury caused by a one-off incident or is it an over-use injury? (please circle)
    - One-off incident
    - Over-use injury

38. If one-off incident, please describe how the injury occurred.

____

____

____

____

39. Do you feel as though any of your past of current injuries are affecting the way you are currently executing your classical ballet technique? (Yes / No)

40. If yes, please describe how your injuries are currently affecting your classical ballet technique.

____

____

____

____

Thank you for completing this questionnaire.

Appendix E: Chapter 3 - Additional Information on Cubic Spline Curve Interpolation

Interpolation ("gap filling") of the kinematic data was achieved using cubic spline curve interpolation, The interpolation procedure was run using the Vicon Workstation software". The term "spline" has its origins in a pliable strip of wood or rubber used by draftsmen in patterning curves, but the mathematical form was popularised as an approximation procedure during the 1960s when it was shown that a spline function was the smoothest of all functions for fitting N data within specified limits (Reinsch, 1967).

In general, one need only specify the degree of the spline, the required accuracy of the fit, and the number and positions of the knots. Spline functions are an extremely useful analytical tool for biomechanists, as they are the ideal interpolative function to use when a set of time histories must be synchronised in order to process data (Wood, 1982). Specific detail on the cubic spine function is provided below.

The cubic spine function is a form of interpolation where the interpolant is a special type of polynomial called a "spline" (Wood & Jennings, 1979). A "spline" consists of a number of polynomials, all of some low degree m, that are "pieced" together at points in time called "knots" (x_j: j = 1, 2, ...n) and joined in such a way as to provide a continuous function g(t) with m-1 continuous derivatives. When m equals 3, as is most common, the resulting cubic spline function consists of n-1 cubic polynomials, each of the form

$$g(t) = p_j(t) = a_j + b_j(t) + c_j(t)^2 + d_j(t)^3$$

spanning an interval $x_{j-1} \leq t < x_j$ and satisfying the continuity condition

$$p^k_j (x_j) = p^k_{j+1}; (k = 0,1,2; j = 1,2,......n)$$

where p^k_j denotes the k^{th} derivative of the j^{th} polynomial piece. The condition by which the function has m-1 continuous derivatives ensures that it is smooth itself but, unlike a global polynomial, its "piecewise" nature enables it to adapt quickly to changes in curvature (Wood, 1982).

Appendix F: Chapter 3 - Additional Information on Woltring General Cross-Validatory (GCV) Quintic Spline Routine

Woltring's general cross-validatory (GCV) quintic spline routine (Woltring, 1985; Woltring, 1986) was used for the filtering process. As previously indicate in Appendix E, spline functions are a series of polynomial curves through one or more points joined (or pieced together) at points called “knots”. Many spline techniques are derived from the work of Reinsch (1967) and have a knot at each data point, therefore requiring the use to choose optimal knot positions. That is, the user has to specify a weighting factor for each data point, and select the value of the smoothing parameter which controls the extent of the smoothing.

The GCV quintic spline routine does not require the user to specify the amount of error in the data to be smoothed, but instead automatically selects an optimum smoothing parameter (Wolting, 1985), thereby allowing selective filtering of the data signal more where it is required, and less where it does not require as much. The GCV quintic spline routine can thus accommodate data points sampled at unequal time intervals.

If λ is a smoothing parameter controlling the trade-off between the smoothness of the estimate and the goodness of fit, then $V(\lambda)$ is the GCV estimate of the smoothing parameter.

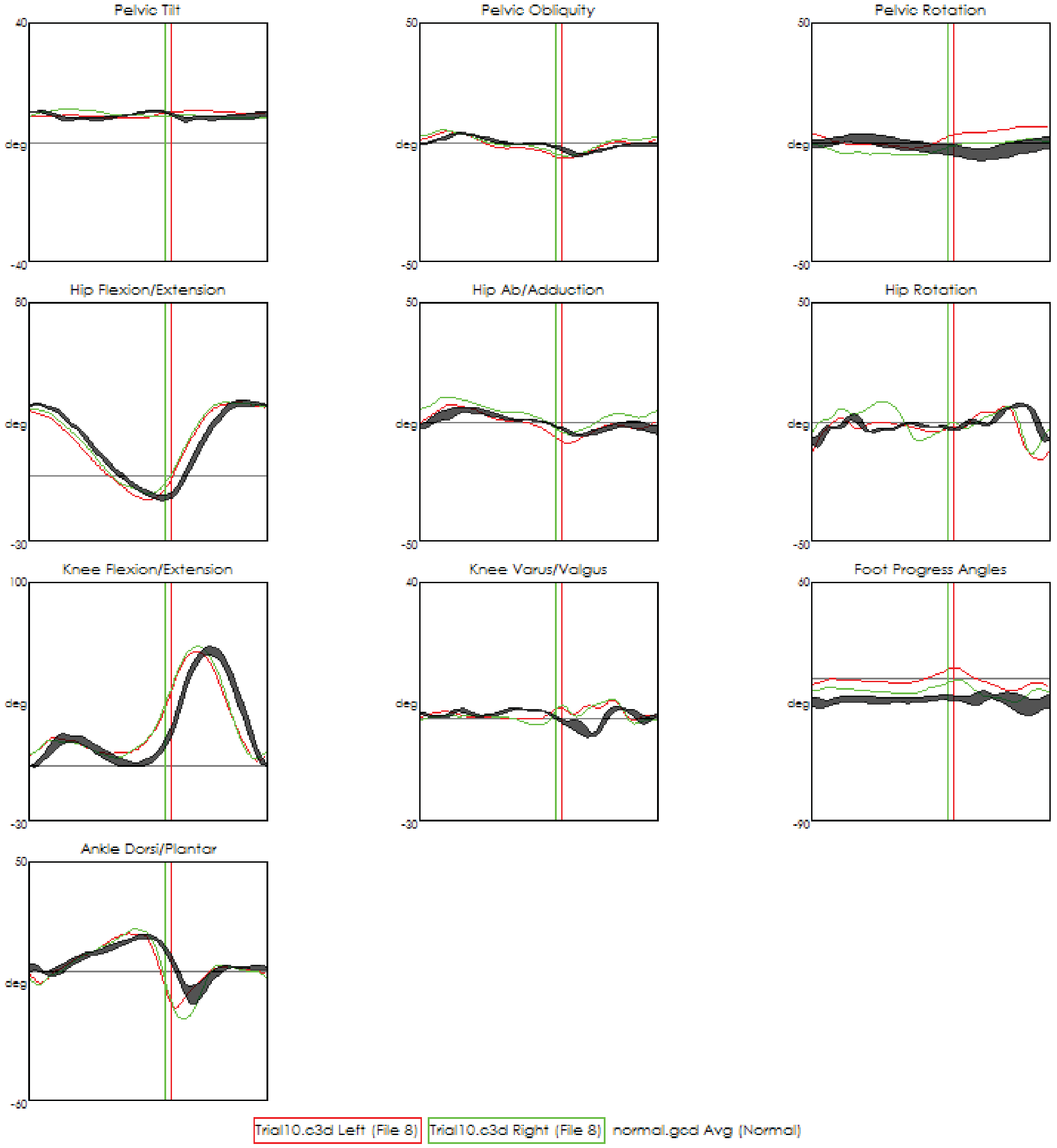
For $\lambda < \infty$, the GCV function is:

$$V(\lambda) = \frac{\sum_{\nu=1}^{n-M} \tilde{z}_{\nu}^{2} / (1 + \tilde{\lambda}_{\nu n}/n\lambda)^2}{[\sum_{\nu=1}^{n-M} 1/(1 + \tilde{\lambda}_{\nu n}/n\lambda)]^2}$$

(Liu *et al.*, 2004)

The Woltring GCV filter was run using the Vicon Workstation software.

Appendix G: Chapter 3 - Graphical Outputs for Gait Data Displayed in Vicon Polygon Authoring Tool



Shaded area represents mean "normal" adult gait data ± 1 standard deviation

Appendix H: Chapter 3 - Summary of Descriptive Statistics for Kinematic Variables

Descriptive Statistics for Thorax Anterior/Posterior Tilt

			Thorax Anterior-Posterior Tilt					
Movement Category	**Step**	**Time point**	**Non-professionals (NP) (N=11)**		**Professionals (PR) (N=11)**		**Mean Difference (°) (NP - PR)**	**t-test**
			Mean (±SD) (°)	**CV**	**Mean (±SD) (°)**	**CV**		**p-value**
Bend (*Plié*)	*Grand Plié 1st Position*	Start	-7.1 (±6.7)	0.94	-12.1(±3.4)	0.28	5.0	**0.040***
		Peak	4.5 (±8.2)	1.82	-2.6 (±6.7)	2.58	7.1	**0.039***
	Grand Plié 2nd Position	Start	-7.2 (±6.8)	0.94	-12.4 (±3.4)	0.27	5.2	**0.036***
		Peak	4.5 (±9.4)	2.09	-0.5 (±4.7)	9.40	5.0	0.136
Stretch (*Battement*)	*Battement Tendu Back*	Start	-6.9 (±2.1)	0.30	-6.8 (±5.3)	0.78	-0.1	0.958
		Peak	-7.6 (±2.4)	0.32	-7.6 (±5.0)	0.66	0.0	1.000
	Battement Jeté 45° Front	Start	-8.7 (±3.3)	0.38	-6.5 (±6.0)	0.92	-2.2	0.286
		Peak	-7.0 (±3.8)	0.54	-6.2 (±6.0)	0.97	-0.8	0.707
Rise (*Relevé*)	*Rise 1st Position*	Start	-7.1 (±2.7)	2.63	-5.7 (±5.7)	1.00	-1.4	0.480
		Peak	-7.3 (±2.6)	0.36	-6.8 (±6.3)	0.93	-0.5	0.827
	Rise 2nd Position	Start	-6.8 (±2.5)	0.37	-8.3 (±2.0)	0.24	1.5	0.142
		Peak	-7.5 (±2.5)	0.33	-8.9 (±2.5)	0.28	1.4	0.185
Jump (*Sauté*)	*Sauté 1st Position*	Start	-0.5 (±4.3)	8.60	1.3 (±4.8)	3.69	-1.8	0.383
		Peak	-6.9 (±1.7)	0.25	-9.1 (±3.3)	0.36	2.2	0.067
	Temps Levé	Start	0.0 (±3.3)	-	0.9 (±4.8)	5.33	-0.9	0.607
		Peak	-5.1 (±3.5)	0.69	-9.2 (±3.0)	0.33	4.1	**0.008***
Glide (*Glisse*)	*Glissade Under*	Start	-3.4 (±4.8)	1.41	-4.5 (±4.3)	0.96	1.1	0.582
		Peak	-1.2 (±3.8)	3.17	-4.3 (±4.4)	1.02	3.1	0.091
	Glissade Over	Start	-4.3 (±3.0)	0.70	-6.6 (±3.4)	0.52	2.3	0.111
		Peak	-0.2 (±3.5)	17.50	-2.6 (±4.0)	1.54	2.4	0.156
Dart (*Elancé*)	*Jeté Ordinaire*	Start	3.4 (±4.3)	1.26	2.7 (±5.9)	2.19	0.7	0.777
		Peak	-3.6 (±3.2)	0.89	-6.9 (±5.2)	0.75	3.3	0.084
	Grand Jeté Elancé En Avants	Start	1.6 (±5.0)	3.13	-1.0 (±9.1)	9.10	2.6	0.411
		Peak	-2.7 (±7.0)	2.59	-3.8 (±11.4)	3.00	1.1	0.789
Turn (*Tour*)	*Double Pirouette En Dehors*	Start	-2.9 (±5.6)	1.93	-0.9 (±4.3)	4.78	-2.0	0.362
		Peak	1.2 (±6.7)	5.58	0.3 (±8.1)	27.00	0.9	0.777
	Double Pirouette En Dedans	Start	3.4 (±6.5)	1.91	6.7 (±5.7)	0.85	-3.3	0.210
		Peak	-2.9 (±6.5)	2.24	1.1 (±7.2)	6.55	-4.0	0.185

SD = Standard Deviation
CV = Coefficient of Variation
**** Significant difference between non-professional and professional groups (t-test: p<0.05).***

Appendix H continued:

Descriptive Statistics for Thorax Side Tilt

			Thorax Side Tilt					
Movement Category	**Step**	**Time point**	**Non-professionals (NP) (N=13)**		**Professionals (PR) (N=12)**		**Mean Difference (°) (NP - PR)**	**t-test**
			Mean (±SD) (°)	**CV**	**Mean (±SD) (°)**	**CV**		**p-value**
Bend (*Plié*)	*Grand Plié 1st Position*	Start	-0.5 (±1.9)	3.80	0.5 (±1.7)	3.40	-1.0	0.252
		Peak	0.8 (±2.9)	3.63	0.0 (±1.9)	-	0.8	0.438
	Grand Plié 2nd Position	Start	0.1 (±1.9)	19.00	0.0 (±2.0)	-	0.1	0.917
		Peak	0.3 (±2.5)	8.33	0.2 (±1.9)	9.50	0.1	0.925
Stretch (*Battement*)	*Battement Tendu Back*	Start	0.8 (±1.8)	2.25	1.1 (±2.1)	1.91	-0.3	0.747
		Peak	0.5 (±1.7)	3.40	0.7 (±2.1)	3.00	-0.2	0.738
	Battement Jeté 45° Front	Start	-0.2 (±1.2)	6.00	-0.7 (±2.0)	2.86	0.5	0.436
		Peak	-0.5 (±1.4)	2.80	-0.7 (±2.1)	3.00	0.2	0.809
Rise (*Relevé*)	*Rise 1st Position*	Start	0.2 (±1.4)	7.00	0.5 (±1.2)	2.40	-0.3	0.631
		Peak	0.3 (±1.6)	5.33	0.6 (±1.8)	3.00	-0.3	0.624
	Rise 2nd Position	Start	0.2 (±1.4)	7.00	0.3 (±1.4)	4.67	-0.1	0.881
		Peak	0.5 (±1.6)	3.20	0.5 (±1.6)	3.20	0.0	1.000
Jump (*Sauté*)	*Sauté 1st Position*	Start	0.5 (±1.4)	2.80	0.7 (±1.2)	1.71	-0.2	0.634
		Peak	-0.5 (±1.3)	2.60	-0.4 (±2.4)	6.00	-0.1	0.914
	Temps Levé	Start	-8.4 (±3.7)	0.44	-6.5 (±2.5)	2.00	-1.9	0.194
		Peak	-4.8 (±3.0)	0.63	-3.1 (±2.6)	0.38	-1.7	0.166
Glide (*Glisse*)	*Glissade Under*	Start	2.0 (±7.0)	3.50	3.5 (±9.5)	2.71	-1.5	0.668
		Peak	-6.3 (±3.1)	0.49	-6.5 (±5.2)	0.80	0.2	0.922
	Glissade Over	Start	-1.2 (±4.8)	4.00	1.9 (±8.6)	4.53	-3.1	0.310
		Peak	-5.7 (±3.1)	0.54	-7.5 (±4.9)	0.65	1.8	0.331
Dart (*Elancé*)	*Jeté Ordinaire*	Start	0.5 (±3.6)	7.20	0.1 (±2.0)	20.00	0.4	0.771
		Peak	-2.4 (±3.9)	1.63	-0.4 (±2.1)	5.25	-2.0	0.147
	Grand Jeté Elancé En Avants	Start	5.7 (±4.2)	0.74	5.0 (±4.2)	0.84	0.7	0.689
		Peak	2.5 (±3.1)	1.24	-5.7 (±7.2)	1.26	8.2	**0.002***
Turn (*Tour*)	*Double Pirouette En Dehors*	Start	3.5 (±7.8)	2.23	4.2 (±6.8)	1.62	-0.7	0.797
		Peak	-3.9 (±6.3)	1.62	-2.7 (±5.1)	1.89	-1.2	0.635
	Double Pirouette En Dedans	Start	-3.5 (±6.8)	1.94	-1.6 (±4.5)	2.81	-1.9	0.449
		Peak	0.9 (±6.4)	7.11	-0.5 (±8.5)	17.00	0.4	0.655

SD = Standard Deviation
CV = Coefficient of Variation
**** Significant difference between non-professional and professional groups (t-test: p<0.05).***

Appendix H continued:

Descriptive Statistics for Pelvic Anterior-Posterior Tilt

			Pelvic Anterior-Posterior Tilt					
Movement Category	**Step**	**Time point**	**Non-professionals (NP) (N=13)**		**Professionals (PR) (N=12)**		**Mean Difference (°) (NP - PR)**	**t-test**
			Mean (±SD) (°)	**CV**	**Mean (±SD) (°)**	**CV**		**p-value**
Bend (*Plié*)	*Grand Plié 1st Position*	Start	16.6 (±4.6)	0.28	15.2 (±4.4)	0.29	1.4	0.434
		Peak	10.4 (±6.7)	0.64	6.1 (±4.8)	0.79	4.3	0.080
	Grand Plié 2nd Position	Start	15.3 (±3.9)	0.25	13.8 (±5.4)	0.39	1.5	0.410
		Peak	11.4 (±6.8)	0.60	6.1 (±7.1)	1.16	5.3	0.066
Stretch (*Battement*)	*Battement Tendu Back*	Start	21.1 (±3.7)	0.18	18.7 (±4.4)	0.24	2.4	0.164
		Peak	30.5 (±3.9)	0.13	28.8 (±4.4)	0.15	1.7	0.313
	Battement Jeté 45° Front	Start	15.4 (±3.3)	0.21	15.1 (±4.2)	0.28	0.3	0.841
		Peak	7.8 (±4.2)	0.54	5.6 (±4.6)	0.82	2.2	0.212
Rise (*Relevé*)	*Rise 1st Position*	Start	20.2 (±3.6)	0.18	17.8 (±3.4)	0.19	2.4	0.100
		Peak	19.6 (±3.6)	0.18	15.9 (±3.1)	0.19	3.7	**0.012***
	Rise 2nd Position	Start	19.2 (±4.3)	0.22	16.5 (±3.5)	0.21	2.7	0.104
		Peak	18.5 (±4.4)	0.24	15.1 (±4.2)	0.28	3.4	0.051
Jump (*Sauté*)	*Sauté 1st Position*	Start	22.1 (±3.3)	0.15	19.4 (±5.4)	0.28	2.7	0.145
		Peak	17.3 (±4.3)	0.25	17.7 (±4.9)	0.28	0.2	0.846
	Temps Levé	Start	20.2 (±4.2)	0.21	21.4 (±3.8)	0.18	-1.2	0.468
		Peak	17.6 (±4.4)	0.25	17.8 (±4.5)	0.25	-0.2	0.940
Glide (*Glisse*)	*Glissade Under*	Start	-4.5 (±2.5)	0.56	-1.8 (±3.8)	2.11	-2.7	**0.044***
		Peak	-0.6 (±3.8)	6.33	-0.2 (±2.9)	14.50	-0.4	0.748
	Glissade Over	Start	-3.8 (±2.9)	0.76	-0.4 (±5.3)	13.25	-3.4	0.055
		Peak	1.8 (±3.3)	1.83	-0.5 (±4.1)	8.20	2.3	0.131
Dart (*Elancé*)	*Jeté Ordinaire*	Start	20.5 (±4.6)	0.22	21.1 (±5.2)	0.25	-0.6	0.816
		Peak	20.1 (±3.6)	0.18	19.1 (±5.4)	0.28	1.0	0.587
	Grand Jeté Elancé En Avants	Start	15.5 (±5.7)	0.37	14.8 (±5.7)	0.39	0.7	0.732
		Peak	24.8 (±4.5)	0.18	28.1 (±4.6)	0.16	-3.3	0.095
Turn (*Tour*)	*Double Pirouette En Dehors*	Start	-2.5 (±11.4)	4.56	-7.6 (±9.5)	1.25	5.1	0.238
		Peak	0.8 (±10.2)	12.75	-2.9 (±16.3)	5.62	3.7	0.501
	Double Pirouette En Dedans	Start	-15.5 (±11.2)	0.72	-12.3 (±9.7)	0.79	-3.2	0.454
		Peak	5.4 (±14.6)	2.70	-2.4 (±12.7)	5.29	-3.0	0.168

SD = Standard Deviation
CV = Coefficient of Variation
**** Significant difference between non-professional and professional groups (t-test: p<0.05).***

Appendix H continued:

Descriptive Statistics for Pelvic Obliquity

			Pelvic Obliquity					
Movement Category	**Step**	**Time point**	**Non-professionals (NP) (N=13)**		**Professionals (PR) (N=12)**		**Mean Difference (°) (NP - PR)**	**t-test**
			Mean (±SD) (°)	**CV**	**Mean (±SD) (°)**	**CV**		**p-value**
Bend (*Plié*)	*Grand Plié 1st Position*	Start	0.3 (±2.3)	7.67	0.8 (±1.2)	1.50	-0.5	0.552
		Peak	0.1 (±1.7)	17.00	0.3 (±1.4)	4.67	-0.2	0.786
	Grand Plié 2nd Position	Start	0.2 (±1.8)	9.00	0.0 (±1.7)	-	0.2	0.745
		Peak	0.1 (±2.3)	23.00	-0.1 (±1.8)	18.00	0.2	0.846
Stretch (*Battement*)	*Battement Tendu Back*	Start	2.8 (±2.2)	0.79	3.3 (±1.5)	0.45	-0.5	0.46
		Peak	1.2 (±2.9)	2.42	0.5 (±1.2)	2.40	0.7	0.427
	Battement Jeté 45° Front	Start	1.8 (±2.4)	1.33	1.9 (±1.0)	0.53	-0.1	0.926
		Peak	9.3 (±3.1)	0.33	9.3 (±2.6)	0.28	0.0	0.982
Rise (*Relevé*)	*Rise 1st Position*	Start	0.2 (±2.0)	10.00	1.0 (±1.3)	1.30	-0.8	0.237
		Peak	0.0 (±1.9)	-	0.5 (±1.0)	2.00	-0.5	0.419
	Rise 2nd Position	Start	0.0 (±2.0)	-	1.0 (±1.2)	1.20	-1.0	0.142
		Peak	0.2 (±2.0)	10.00	0.9 (±1.2)	1.33	-1.1	0.274
Jump (*Sauté*)	*Sauté 1st Position*	Start	-0.2 (±2.1)	10.50	0.6 (±2.3)	3.83	-0.8	0.405
		Peak	0.0 (±2.3)	-	0.2 (±1.6)	8.00	-0.2	0.987
	Temps Levé	Start	-1.7 (±4.7)	2.76	1.1 (±3.6)	3.27	-2.8	0.112
		Peak	-12.4 (±3.8)	3.26	-10.8 (±3.1)	0.29	-1.6	0.257
Glide (*Glisse*)	*Glissade Under*	Start	18.5 (±4.7)	0.25	18.5 (±4.9)	0.26	0.0	0.984
		Peak	16.3 (±4.7)	0.24	15.3 (±6.3)	0.41	1.0	0.663
	Glissade Over	Start	18.7 (±4.5)	0.24	17.6 (±4.3)	0.24	1.1	0.534
		Peak	18.2 (±3.7)	0.20	16.8 (±4.8)	0.29	1.4	0.397
Dart (*Elancé*)	*Jeté Ordinaire*	Start	6.9 (±3.3)	0.48	3.9 (±3.8)	0.97	3.0	**0.046***
		Peak	4.4 (±4.0)	0.91	4.5 (±3.0)	0.67	-0.1	0.936
	Grand Jeté Elancé En Avants	Start	2.8 (±4.6)	1.64	2.1 (±5.2)	2.48	0.7	0.702
		Peak	4.6 (±4.9)	1.07	5.1 (±6.4)	1.25	-0.5	0.839
Turn (*Tour*)	*Double Pirouette En Dehors*	Start	-10.2 (±7.4)	0.73	-8.4 (±9.8)	1.17	-1.8	0.605
		Peak	12.2 (±10.5)	0.86	8.6 (±12.8)	1.49	3.6	0.441
	Double Pirouette En Dedans	Start	8.1 (±9.3)	1.15	4.8 (±9.6)	2.00	3.3	0.399
		Peak	-3.2 (±15.0)	0.21	-2.1 (±14.6)	6.95	-1.1	0.859

SD = Standard Deviation
CV = Coefficient of Variation
**** Significant difference between non-professional and professional groups (t-test: p<0.05).***

Appendix H continued:

Descriptive Statistics for Pelvic - Thoracic Transverse Rotation

			Pelvic - Thoracic Transverse Rotation					
Movement Category	Step	Time point	Non-professionals (NP) (N=13)		Professionals (PR) (N=12)		Mean Difference (°) (NP - PR)	t-test
			Mean (±SD) (°)	CV	Mean (±SD) (°)	CV		p-value
Bend (*Plié*)	*Grand Plié 1st Position*	Start	-0.3 (±2.0)	6.67	0.8 (±3.2)	0.40	-1.1	0.348
		Peak	-0.1 (±2.7)	27.00	-0.6 (±2.7)	4.50	0.5	0.703
	Grand Plié 2nd Position	Start	0.1 (±2.1)	21.00	-0.1 (±2.4)	24.00	0.2	0.853
		Peak	-0.3 (±3.1)	10.33	-1.1 (±2.6)	2.36	0.8	0.512
Stretch (*Battement*)	*Battement Tendu Back*	Start	-1.5 (±3.5)	2.33	0.6(±3.0)	5.00	-2.1	0.152
		Peak	-6.6 (±3.2)	0.48	-9.2 (±3.4)	0.37	2.6	0.077
	Battement Jeté 45° Front	Start	-1.8 (±2.7)	1.50	-1.9 (±3.0)	1.58	0.1	0.941
		Peak	1.5 (±4.3)	2.87	5.7 (±3.1)	0.54	-4.2	**0.041***
Rise (*Relevé*)	*Rise 1st Position*	Start	0.4 (±3.2)	8.00	0.3 (±2.4)	8.00	0.1	0.941
		Peak	0.9 (±2.6)	2.89	0.0 (±2.6)	-	0.9	0.421
	Rise 2nd Position	Start	0.1 (±2.7)	27.00	0.5 (±2.2)	4.40	-0.4	0.731
		Peak	0.0 (±2.2)	-	0.4 (±2.8)	7.00	-0.4	0.74
Jump (*Sauté*)	*Sauté 1st Position*	Start	-0.1 (±2.6)	26.00	-0.6 (±2.7)	4.50	0.5	0.638
		Peak	-0.6 (±3.3)	5.50	-0.6 (±3.4)	5.67	0.0	1.000
	Temps Levé	Start	-2.3 (±4.9)	2.13	-3.6 (±3.2)	0.89	1.3	0.477
		Peak	-2.9 (±4.6)	1.59	-2.3 (±4.7)	2.04	-0.6	0.751
Glide (*Glisse*)	*Glissade Under*	Start	-3.1 (±5.8)	1.87	-1.0 (±3.8)	3.80	-2.1	0.329
		Peak	-0.7 (±4.3)	6.14	2.9 (±5.0)	1.72	-3.6	0.287
	Glissade Over	Start	-6.7 (±4.2)	0.63	-4.7 (±5.6)	1.19	-2.0	0.354
		Peak	1.6 (±3.9)	2.44	-1.0 (±4.2)	4.20	0.8	0.156
Dart (*Elancé*)	*Jeté Ordinaire*	Start	-3.6 (±4.3)	1.19	-4.4 (±3.6)	0.82	0.8	0.634
		Peak	-3.6 (±4.7)	1.31	-2.4 (±2.8)	1.17	-1.2	0.446
	Grand Jeté Elancé En Avants	Start	2.7 (±7.1)	2.63	-7.7 (±8.5)	0.56	10.4	**0.005***
		Peak	32.5 (±5.8)	0.18	21.6 (±9.8)	0.45	10.9	**0.005***
Turn (*Tour*)	*Double Pirouette En Dehors*	Start	-2.9 (±5.6)	1.93	-0.9 (±4.3)	4.78	-2.0	0.362
		Peak	1.2 (±6.7)	5.58	0.3 (±8.1)	27.00	0.9	0.777
	Double Pirouette En Dedans	Start	3.4 (±6.5)	1.91	6.7 (±5.7)	0.85	-3.3	0.21
		Peak	-2.9 (±6.5)	2.24	1.1 (±7.2)	6.55	-4.0	0.185

SD = Standard Deviation
CV = Coefficient of Variation
**** Significant difference between non-professional and professional groups (t-test: p<0.05).***

Appendix H continued:

Descriptive Statistics for Hip Transverse Rotation

			Hip Transverse Rotation					
Movement Category	**Step**	**Time point**	**Non-professionals (NP) (N=13)**		**Professionals (PR) (N=12)**		**Mean Difference (°) (NP - PR)**	**t-test**
			Mean (±SD) (°)	**CV**	**Mean (±SD) (°)**	**CV**		**p-value**
Bend (*Plié*)	*Grand Plié 1st Position*	Start	-11.9 (±2.8)	0.24	-17.8 (±6.6)	0.37	5.9	**0.008***
		Peak	-21.7 (±7.9)	0.36	-23.4 (±11.3)	0.48	1.7	0.660
	Grand Plié 2nd Position	Start	-20.8 (±6.2)	0.30	-28.8 (±6.4)	0.22	8.0	**0.004***
		Peak	-27.5 (±8.2)	0.30	-25.3 (±13.8)	0.55	-2.2	0.615
Stretch (*Battement*)	*Battement Tendu Back*	Start	-14.9 (±5.0)	0.34	-22.2 (±6.2)	0.28	7.3	**0.004***
		Peak	-17.2 (±2.4)	0.14	-24.8 (±6.7)	0.27	7.6	**0.001***
	Battement Jeté 45° Front	Start	-9.5 (±3.8)	0.40	-17.3 (±6.8)	0.39	7.8	**0.002***
		Peak	-23.6 (±4.3)	0.18	-30.3 (±7.6)	0.25	6.7	**0.012***
Rise (*Relevé*)	*Rise 1st Position*	Start	-12.3 (±4.0)	0.33	-17.5 (±5.7)	0.33	5.2	**0.014***
		Peak	-17.7 (±2.3)	0.13	-23.6 (±7.0)	0.30	5.9	**0.009***
	Rise 2nd Position	Start	-19.0 (±4.2)	0.22	-22.6 (±6.1)	0.27	3.6	0.099
		Peak	-25.0 (±4.4)	0.18	-30.8 (±5.7)	0.19	5.8	**0.010***
Jump (*Sauté*)	*Sauté 1st Position*	Start	-20.6 (±4.8)	0.23	-20.8 (±6.0)	0.29	0.2	0.951
		Peak	-25.5 (±4.2)	0.16	-32.0 (±8.4)	0.26	6.5	**0.021***
	Temps Levé	Start	-9.5 (±4.5)	0.47	-10.3 (±5.8)	0.56	0.8	0.734
		Peak	-26.9 (±5.7)	0.21	-32.2 (±7.1)	0.22	5.3	0.052
Glide (*Glisse*)	*Glissade Under*	Start	-16.2 (±5.3)	0.33	-23.6 (±6.8)	0.29	7.4	**0.006***
		Peak	-37.8 (±6.7)	0.18	-39.0 (±11.1)	0.28	1.2	0.738
	Glissade Over	Start	-12.4 (±7.2)	0.58	-18.0 (±6.7)	0.37	5.6	0.055
		Peak	-36.5 (±5.5)	0.15	-41.2 (±10.5)	0.25	4.7	0.171
Dart (*Elancé*)	*Jeté Ordinaire*	Start	-29.4 (±5.9)	0.20	-25.8 (±9.3)	0.36	-3.6	0.262
		Peak	-24.8 (±5.4)	0.22	-30.1 (±8.0)	0.27	5.3	0.062
	Grand Jeté Elancé En Avants	Start	1.8 (±5.4)	3.00	-3.8 (±4.8)	1.26	5.6	**0.013***
		Peak	-2.2 (±10.6)	4.82	3.3 (±12.7)	3.85	-5.5	0.258
Turn (*Tour*)	*Double Pirouette En Dehors*	Start	-14.1 (±7.6)	0.54	-19.4 (±7.0)	0.36	5.3	0.083
		Peak	-12.6 (±6.9)	0.55	-21.3 (±6.8)	0.32	8.7	**0.005***
	Double Pirouette En Dedans	Start	-12.4 (±4.7)	0.38	-19.5 (±8.0)	0.41	7.1	**0.012***
		Peak	-15.2 (±3.4)	0.22	-21.5 (±5.5)	0.26	6.3	**0.002***

SD = Standard Deviation
CV = Coefficient of Variation
**** Significant difference between non-professional and professional groups (t-test: p<0.05).***

Appendix H continued:

Descriptive Statistics for Ankle Transverse Rotation

			Ankle Transverse Rotation					
Movement Category	**Step**	**Time point**	**Non-professionals (NP) (N=13)**		**Professionals (PR) (N=12)**		**Mean Difference (°) (NP - PR)**	**t-test**
			Mean (±SD) (°)	**CV**	**Mean (±SD) (°)**	**CV**		**p-value**
Bend (*Plié*)	*Grand Plié 1st Position*	Start	-16.8 (±8.3)	0.49	-16.3 (±5.0)	0.31	-0.5	0.899
		Peak	5.5 (±10.6)	1.93	-1.9 (±11.3)	5.95	7.4	0.217
	Grand Plié 2nd Position	Start	-7.1 (±6.5)	0.92	-10.0 (±5.3)	0.53	2.9	0.367
		Peak	-15.9 (±12.0)	0.75	-13.7 (±5.8)	0.42	-2.2	0.673
Stretch (*Battement*)	*Battement Tendu Back*	Start	-13.1 (±6.3)	0.48	-17.6 (±7.5)	0.43	4.5	0.234
		Peak	2.0 (±4.2)	2.10	1.4 (±4.2)	3.00	3.3	0.797
	Battement Jeté 45° Front	Start	-16.8 (±7.8)	0.46	-20.1 (±5.3)	0.26	3.3	0.348
		Peak	4.3 (±5.3)	1.23	4.0 (±4.3)	1.08	0.3	0.922
Rise (*Relevé*)	*Rise 1st Position*	Start	-11.3 (±8.5)	0.75	-15.4 (±3.6)	0.23	4.1	0.250
		Peak	7.9 (±4.5)	0.71	1.6 (±2.7)	1.69	6.3	**0.007***
	Rise 2nd Position	Start	-6.3 (±7.8)	1.24	-13.9 (±3.3)	0.24	7.6	**0.032***
		Peak	7.8 (±5.1)	0.65	1.1 (±2.6)	2.36	6.7	**0.009***
Jump (*Sauté*)	*Sauté 1st Position*	Start	-30.9 (±7.2)	0.23	-36.9 (±10.0)	0.27	6.0	0.201
		Peak	5.9 (±5.1)	0.86	6.6 (±4.2)	0.64	-0.7	0.78
	Temps Levé	Start	-29.5 (±12.0)	0.71	-40.7 (±9.8)	0.24	11.2	0.072
		Peak	5.1 (±4.0)	0.78	2.6 (±5.4)	2.08	2.5	0.312
Glide (*Glisse*)	*Glissade Under*	Start	-27.4 (±7.2)	0.26	-35.7 (±6.2)	0.17	8.3	**0.033***
		Peak	3.3 (±4.5)	1.36	-2.4 (±7.3)	3.04	5.7	0.090
	Glissade Over	Start	-26.6 (±11.7)	0.44	-35.3 (±6.6)	0.19	8.7	0.107
		Peak	2.0 (±3.2)	1.60	-1.1 (±6.2)	5.64	3.1	0.230
Dart (*Elancé*)	*Jeté Ordinaire*	Start	4.0 (±4.8)	1.20	0.9 (±6.6)	7.33	3.1	0.309
		Peak	4.6 (±2.4)	0.52	5.1 (±5.8)	1.08	-0.5	0.820
	Grand Jeté Elancé En Avants	Start	0.4 (±8.8)	22.00	1.9 (±6.4)	3.37	-1.5	0.718
		Peak	7.6 (±6.7)	0.88	7.7 (±8.4)	1.09	-0.1	0.982
Turn (*Tour*)	*Double Pirouette En Dehors*	Start	-0.8 (±5.0)	62.50	-9.0 (±5.1)	0.57	8.2	**0.007***
		Peak	-3.1 (±9.5)	3.06	-3.9 (±6.3)	1.62	0.8	0.866
	Double Pirouette En Dedans	Start	11.4 (±7.8)	0.68	3.4 (±6.8)	2.00	8.0	0.057
		Peak	15.0 (±6.8)	0.45	10.4 (±7.2)	0.69	4.6	0.229

SD = Standard Deviation
CV = Coefficient of Variation
**** Significant difference between non-professional and professional groups (t-test: p<0.05).***

Appendix H continued:

Descriptive Statistics for Knee Extension

Movement Category	Step	Time point	Knee Extension: Non-professionals (NP) (N=13) Mean (±SD) (°)	CV	Professionals (PR) (N=12) Mean (±SD) (°)	CV	Mean Difference (°) (NP - PR)	t-test p-value
Bend (*Plié*)	*Grand Plié 1st Position*	Start	-6.4 (±3.7)	0.58	-10.4 (±3.8)	0.37	4.0	**0.014***
		Peak	n/a	n/a	n/a	n/a	n/a	n/a
	Grand Plié 2nd Position	Start	-9.3 (±3.2)	0.34	-12.3 (±3.5)	0.28	3.0	**0.039***
		Peak	n/a	n/a	n/a	n/a	n/a	n/a
Stretch (*Battement*)	*Battement Tendu Back*	Start	-4.5 (±3.6)	0.80	-8.9 (±5.3)	0.60	4.4	**0.021***
		Peak	-3.9 (±2.0)	0.51	-6.5 (±3.8)	0.58	2.6	**0.044***
	Battement Jeté 45° Front	Start	-2.8 (±4.5)	1.61	-8.8 (±5.2)	0.59	6.0	**0.005***
		Peak	-5.8 (±3.3)	0.57	-8.7 (±3.1)	0.36	2.9	**0.040***
Rise (*Relevé*)	*Rise 1st Position*	Start	-5.6 (±3.5)	0.63	-8.8 (±4.9)	0.56	3.2	0.078
		Peak	-7.4 (±3.3)	0.45	-8.6 (±4.4)	0.51	1.2	0.447
	Rise 2nd Position	Start	-10.2 (±3.8)	0.37	-12.8 (±4.2)	0.33	2.6	0.130
		Peak	-8.2 (±5.2)	0.63	-10.1 (±4.5)	0.45	1.9	0.348
Jump (*Sauté*)	*Sauté 1st Position*	Start	n/a	n/a	n/a	n/a	n/a	n/a
		Peak	-6.5 (±2.5)	0.38	-8.3 (±3.1)	0.37	1.8	0.144
	Temps Levé	Start	n/a	n/a	n/a	n/a	n/a	n/a
		Peak	-5.9 (±2.5)	0.42	-9.8 (±3.0)	0.31	3.9	**0.002***
Glide (*Glisse*)	*Glissade Under*	Start	n/a	n/a	n/a	n/a	n/a	n/a
		Peak	0.5 (±6.5)	13.00	-4.1 (±5.2)	1.27	4.6	0.065
	Glissade Over	Start	n/a	n/a	n/a	n/a	n/a	n/a
		Peak	-3.2 (±3.3)	1.03	-6.4 (±4.4)	0.69	3.2	**0.046***
Dart (*Elancé*)	*Jeté Ordinaire*	Start	n/a	n/a	n/a	n/a	n/a	n/a
		Peak	-4.5 (±3.4)	0.76	-6.6 (±3.0)	0.45	2.1	0.113
	Grand Jeté Elancé En Avants	Start	n/a	n/a	n/a	n/a	n/a	n/a
		Peak	-1.5 (±4.3)	2.87	-7.7 (±5.3)	0.69	6.2	**0.004***
Turn (*Tour*)	*Double Pirouette En Dehors*	Start	-1.8 (±4.9)	2.72	-2.8 (±5.7)	2.04	1.0	0.676
		Peak	2.8 (±10.6)	3.79	0.3 (±12.1)	40.33	2.5	0.597
	Double Pirouette En Dedans	Start	-2.8 (±3.3)	1.18	-6.3 (±4.8)	0.76	3.5	**0.049***
		Peak	-4.2 (±6.4)	1.52	-6.1 (±5.3)	0.87	1.9	0.422

SD = Standard Deviation
CV = Coefficient of Variation
**** Significant difference between non-professional and professional groups (t-test: p<0.05).***

Appendix H continued:

Descriptive Statistics for Ankle Plantarflexion

			Ankle Plantarflexion					
Movement Category	**Step**	**Time point**	**Non-professionals (NP) (N=13)**		**Professionals (N=12)**		**Mean Difference (°) (NP - PR)**	**t-test**
			Mean (±SD) (°)	**CV**	**Mean (±SD) (°)**	**CV**		**p-value**
Bend (*Plié*)	*Grand Plié 1st Position*	Start	n/a	n/a	n/a	n/a	n/a	n/a
		Peak	n/a	n/a	n/a	n/a	n/a	n/a
	Grand Plié 2nd Position	Start	n/a	n/a	n/a	n/a	n/a	n/a
		Peak	n/a	n/a	n/a	n/a	n/a	n/a
Stretch (*Battement*)	*Battement Tendu Back*	Start	n/a	n/a	n/a	n/a	n/a	n/a
		Peak	-52.5 (±5.0)	0.10	-56.7 (±4.8)	0.08	4.2	**0.045***
	Battement Jeté 45° Front	Start	n/a	n/a	n/a	n/a	n/a	n/a
		Peak	-56.5 (±3.9)	0.07	-59.4 (±4.8)	0.08	2.9	0.113
Rise (*Relevé*)	*Rise 1st Position*	Start	n/a	n/a	n/a	n/a	n/a	n/a
		Peak	-48.8 (±2.9)	0.06	-51.7 (±5.0)	0.10	2.9	0.094
	Rise 2nd Position	Start	n/a	n/a	n/a	n/a	n/a	n/a
		Peak	-50.1 (±3.3)	0.07	-52.2 (±3.4)	15.35	2.1	0.132
Jump (*Sauté*)	*Sauté 1st Position*	Start	n/a	n/a	n/a	n/a	n/a	n/a
		Peak	-56.4 (±4.8)	0.09	-59.7 (±4.7)	0.08	3.3	0.099
	Temps Levé	Start	n/a	n/a	n/a	n/a	n/a	n/a
		Peak	-52.2 (±5.4)	0.10	-57.3 (±5.3)	0.09	5.1	**0.026***
Glide (*Glisse*)	*Glissade Under*	Start	n/a	n/a	n/a	n/a	n/a	n/a
		Peak	-52.4 (±4.1)	0.08	-55.9 (±4.9)	0.09	3.5	0.063
	Glissade Over	Start	n/a	n/a	n/a	n/a	n/a	n/a
		Peak	-52.5 (±3.5)	0.07	-56.4 (±4.3)	0.08	3.9	**0.021***
Dart (*Elancé*)	*Jeté Ordinaire*	Start	n/a	n/a	n/a	n/a	n/a	n/a
		Peak	-53.2 (±3.5)	0.07	-56.7 (±5.2)	0.09	3.5	0.058
	Grand Jeté Elancé En Avants	Start	n/a	n/a	n/a	n/a	n/a	n/a
		Peak	-50.5 (±5.1)	0.10	-56.8 (±6.4)	0.11	6.3	**0.012***
Turn (*Tour*)	*Double Pirouette En Dehors*	Start	-38.0 (±7.7)	0.20	-41.2 (±3.6)	0.09	3.2	0.206
		Peak	-25.8 (±19.5)	0.76	-30.8 (±17.0)	0.55	5.0	0.497
	Double Pirouette En Dedans	Start	-39.9 (±6.6)	0.17	-40.2 (±6.8)	0.17	0.3	0.928
		Peak	-38.7 (±10.4)	0.27	-41.7 (±13.2)	0.32	3.0	0.535

SD = Standard Deviation
CV = Coefficient of Variation
**** Significant difference between non-professional and professional groups (t-test: p<0.05).***

Appendix I: Chapter 3 - Summary of Mean Difference in Joint Angle for Steps and Kinematic Variables for which a Statistical Significance was Achieved

	Mean Joint Angle at Start or Peak of Step (°)		
	Non-professionals	**Professionals**	**Difference between non-professional and professional dancers**
Thorax Anterior/Posterior Tilt			
Grand Plié 1st Position - Start	-7.1	-12.1	5.0
Grand Plié 1st Position - Peak	4.5	-2.6	7.1
Grand Plié 2nd Position - Start	-7.2	-12.4	5.2
Temps Levé - Peak	-5.1	-9.2	4.1
		Mean	**5.4**
Thorax Side Tilt			
Grand Jeté Elancé En Avants - Peak	2.5	-5.7	8.2
		Mean	**8.2**
Pelvic Anterior-Posterior Tilt			
Rise 1st Position - Peak	19.6	15.9	3.7
Glissade Under - Start	-4.5	-1.8	2.7
		Mean	**3.2**
Pelvic Obliquity			
Jeté Ordinaire - Start	6.9	3.9	3.0
		Mean	**3.0**
Pelvic - Thoracic Transverse Rotation			
Battement Jeté 45° Front - Peak	1.5	5.7	4.2
Grand Jeté Elancé En Avants - Start	2.7	-7.7	10.4
Grand Jeté Elancé En Avants - Peak	32.5	21.6	10.9
		Mean	**8.5**
Ankle Transverse Rotation			
Rise 1st Position - Peak	7.9	1.6	6.3
Rise 2nd Position - Start	-6.3	-13.9	7.6
Rise 2nd Position - Peak	7.8	1.1	6.7
Glissade Under - Start	-27.4	-35.7	8.3
Double Pirouette En Dehors - Start	-0.8	-9	8.2
		Mean	**7.4**

Appendix I continued:

	Mean Joint Angle at Start or Peak of Step (°)		
	Non-professionals	**Professionals**	**Difference between non-professional and professional dancers**
Hip Transverse Rotation			
Grand Plié 1st Position - Start	-11.9	-17.8	5.9
Grand Plié 2nd Position - Start	-20.8	-28.8	8.0
Battement Tendu Back - Start	-14.9	-22.2	7.3
Battement Tendu Back - Peak	-17.2	-24.2	7.0
Battement Jeté 45° Front - Start	-9.5	-17.3	7.8
Battement Jeté 45° Front - Peak	-23.6	-30.3	6.7
Rise 1st Position - Start	-12.3	-17.5	5.2
Rise 1st Position - Peak	-17.7	-23.6	5.9
Rise 2nd Position - Peak	-20.5	-30.8	10.3
Sauté 1st Position - Peak	-25.5	-32	6.5
Glissade Under - Start	-16.2	-23.6	7.4
Grand Jeté Elancé En Avants - Start	1.8	-3.8	5.6
Double Pirouette En Dehors - Peak	-12.6	-21.3	8.7
Double Pirouette En Dedans - Start	-12.4	-19.5	7.1
Double Pirouette En Dedans - Peak	-15.2	-21.5	6.3
		Mean	**7.0**
Knee Extension			
Grand Plié 1st Position - Start	-6.4	-10.4	4.0
Grand Plié 2nd Position - Start	-9.3	-12.3	3.0
Battement Tendu Back - Start	-4.5	-8.9	4.4
Battement Tendu Back - Peak	-3.9	-6.5	2.6
Battement Jeté 45° Front - Start	-2.8	-8.8	6.0
Battement Jeté 45° Front - Peak	-5.8	-8.7	2.9
Temps Levé - Peak	-5.9	-9.8	3.9
Glissade Over - Peak	-3.2	-6.4	3.2
Grand Jeté Elancé En Avants - Peak	-1.5	-7.7	6.2
Double Pirouette En Dedans - Start	2.8	0.3	2.5
		Mean	**3.9**
Ankle Plantarflexion			
Battement Tendu Back - Peak	-52.5	-56.7	4.2
Temps Levé - Peak	-52.2	-57.3	5.1
Glissade Over - Peak	-52.5	-56.4	3.9
Grand Jeté Elancé En Avants - Peak	-50.5	-56.8	6.3
		Mean	**4.9**

Appendix J: Ethics Approval for Chapter 4 – Accuracy of Qualitative Analysis of Classical Ballet Technique

COPY

THE UNIVERSITY OF
NEW SOUTH WALES

HUMAN RESEARCH ETHICS

9 November 2010

Human Research Ethics Advisory Panel 'H'
Accepted Application

A/Prof Andrew McIntosh
School of Risk and Safety Sciences
UNSW

RE:	**Biomechanical Investigation of the Accuracy of Visual Observation and Efficacy of Verbal Instruction in Classical Ballet Teaching**
Reference Number:	**08/2010/59**
Investigator/s:	**Ms Rachel Ward**

At its meeting on 9th November 2010, the Human Research Ethics Advisory Panel 'H' has recommended to your Head of School and the Human Research Ethics Committee that this project is of minimal ethical impact.

Your request application has been approved for a 12 month period ending 8th November 2011. You may proceed with your research.

....

A/Professor Arthur Ramer
Convener,
Human Research Ethics Advisory Panel 'H'

....

A/Professor Roger Read
Head
School of Chemistry

UNSW SYDNEY NSW 2052
A U S T R A L I A
Telephone: +6 1 (2) 9 3 8 5 4 2 3 4
Facsimile: +6 1 (2) 9 3 8 5 6 6 4 8
Email: ethics. Sec @ unsw. edu. au
Location: Rupert Myers Building,
C/o Research Office / Ethics,
Gate 14, Barker Street, Kensington
A B N 57 195 873 179

Appendix K: Information and Consent Form for Professional Ballet Teachers

THE UNIVERSITY OF
NEW SOUTH WALES

School of Risk and Safety Sciences
School of English, Media & Performing Arts
Approval Number: 08/2010/59

BIOMECHANICAL INVESTIGATION OF THE ACCURACY OF VISUAL OBSERVATION AND EFFICACY OF INSTRUCTION IN CLASSICAL BALLET TEACHING

Information for Participants
Group 3: Professional Ballet Teachers

You (the research participant) are invited to participate in a study investigating the fundamental biomechanical characteristics of classical ballet technique, and the characteristics of effective classical ballet teaching. We (the investigators) hope to determine:

1. If professional/elite classical ballet dancers execute classical ballet technique more closely to the theoretical principles outlined in the dance literature than amateur/non-professional ballet dancers do.
2. The accuracy and efficacy with which ballet teachers visually observe and instruct students of classical ballet.

This study is being conducted by the School of Risk and Safety Sciences and the School of English, Media & Performing Arts at the University of New South Wales (UNSW). The research team will firstly use three-dimensional motion analysis data to compare the movement patterns of amateur/non-professional ballet dancers with professional ballet dancers performing standard classical ballet steps. The study will then use video images and motion analysis data of participating dancers to examine the accuracy with which classical ballet teachers can visually observe the movement patterns executed by the dancers.

You were selected as a possible participant in Group 3 of this study because you are over 18 years of age; and have been or are currently employed as a professional classical ballet teacher.

If you decide to participate in the study, you will be required to attend a group data collection session at the University of New South Wales, Kensington Campus during September 2011. The data collection sessions will take approximately 45 minutes. During this session you will be asked to:

1. Complete a questionnaire outlining your date of birth, dance training and performance history, your ballet teacher training and employment history, and your anatomy and biomechanics training history.

2. Watch a number of video images of dancers performing classical ballet steps, and give your assessment on how technically "correct" each dancer is performing the movement. You will give your assessment of the dancers' technique by responding anonymously to multiple choice questions by use of a hand held remote control device.

Appendix K continued:

THE UNIVERSITY OF
NEW SOUTH WALES

The dancers whose video images you will observe have all given written consent to have their videos used for this purpose.

By signing this consent form, all participating teachers that view video images of participating dancers are agreeing that they will treat any information they see relating to all participating dancers with the strictest of confidence.

Any information that is obtained in connection with this study and that can be identified with you will remain confidential and will be disclosed only with your permission, except as required by law. Your name will not be displayed with or used in reference to any of the information obtained from you as a result of your participation in this study.

If you give us your permission by signing this document, we plan to use data obtained from your responses to the group session questions, and data from your completed questionnaires, for analysis and presentation in a doctoral thesis, it will also be published in local and international journal articles and conference presentations. In any publication, information will be provided in such a way that you cannot be identified.

Complaints may be directed to the Ethics Secretariat, The University of New South Wales, SYDNEY 2052 AUSTRALIA (phone 9385 4234, fax 9385 6648, email ethics.sec@unsw.edu.au). Any complaint you make will be investigated promptly and you will be informed of the outcome.

Feedback regarding the study's findings may be made available through the School of Risk and Safety Sciences' website at www.srss.unsw.edu.au, and through dance and human movement-related publications, including journal articles, magazines, newsletters, and conference presentations and proceedings.

Your decision whether or not to participate will not prejudice your future relations with the University of New South Wales. If you decide to participate, you are free to withdraw your consent and to discontinue participation at any time without prejudice.

If you have any questions, please feel free to ask us. If you have any additional questions later, Rachel Ward (Phone: 0419 273 454; Email: rachel.ward@unsw.edu.au) will be happy to answer them.

You will be given a copy of this form to keep.

Approval No: 08/2010/59 *Biomechanics of Ballet Technique* Version No 2.0, Date: 21 June 11 Page 2 of 3

Appendix K continued:

THE UNIVERSITY OF
NEW SOUTH WALES

School of Risk and Safety Sciences
School of English, Media & Performing Arts
Approval Number: 08/2010/59

BIOMECHANICAL INVESTIGATION OF THE ACCURACY OF VISUAL OBSERVATION AND EFFICACY OF VERBAL INSTRUCTION IN CLASSICAL BALLET TEACHING

PARTICIPANT CONSENT FORM

I,

....

[Please PRINT full name]

have read and understood the Information for Participants on the above named research.

I have been made aware of the procedures involved in the study, including any known or expected inconvenience, risk, discomfort or potential side effect and of their implications as far as they are currently known by the researchers.

I freely choose to participate in this study and understand that I can withdraw at any time.

I also understand that the research study is strictly confidential, and agree that I will not disclose any information about participating dancers whose video images I observe.

I hereby agree to participate in this research study.

....

Signature of Participant

....

Date

Approval No: 08/2010/59 *Biomechanics of Ballet Technique* *Version No 2.0, Date: 21 June 11* Page 3 of 3

Appendix L: Information and Consent Form for Student Ballet Teachers

THE UNIVERSITY OF
NEW SOUTH WALES

School of Risk and Safety Sciences
School of English, Media & Performing Arts
Approval Number: 08/2010/59

BIOMECHANICAL INVESTIGATION OF THE ACCURACY OF VISUAL OBSERVATION AND EFFICACY OF INSTRUCTION IN CLASSICAL BALLET TEACHING

<u>Information for Participants</u>
Group 4: Student Dance Teachers

You (the research participant) are invited to participate in a study investigating the fundamental biomechanical characteristics of classical ballet technique, and the characteristics of effective classical ballet teaching. We (the investigators) hope to determine:

1. If professional/elite classical ballet dancers execute classical ballet technique more closely to the theoretical principles outlined in the dance literature than amateur/non-professional ballet dancers do.
2. The accuracy and efficacy with which ballet teachers visually observe students of classical ballet.

This study is being conducted by the School of Risk and Safety Sciences and the School of English, Media & Performing Arts at the University of New South Wales (UNSW). The research team will firstly use three-dimensional motion analysis data to compare the movement patterns of amateur/non-professional ballet dancers with professional ballet dancers performing standard classical ballet steps. The study will then use video images and motion analysis data of participating dancers to examine the accuracy with which classical ballet teachers can visually observe the movement patterns executed by the dancers.

You were selected as a possible participant in Group 4 of this study because you are over 18 years of age; and are currently enrolled in a dance teacher training program.

If you decide to participate in the study, you will be required to attend a data collection session at the University of New South Wales, Kensington Campus during August 2011. The data collection sessions will take up to 1 hour. During this session you will be asked to:

1. Complete a questionnaire outlining your date of birth, dance training and performance history, your ballet teacher training and employment history, and your anatomy and biomechanics training history.

2. Watch a number of video images of dancers performing classical ballet steps, and give your assessment on how technically "correct" each dancer is performing the movement. You will give your assessment of the dancers' technique by responding anonymously to multiple choice questions by use of a hand held remote control device.

Appendix L continued:

THE UNIVERSITY OF NEW SOUTH WALES

The dancers whose video images you will observe have all given written consent to have their videos used for this purpose.

By signing this consent form, all participating teachers and student teachers that view video images of participating dancers are agreeing that they will treat any information they see relating to all participating dancers with the strictest of confidence.

Any information that is obtained in connection with this study and that can be identified with you will remain confidential and will be disclosed only with your permission, except as required by law. Your name will not be displayed with or used in reference to any of the information obtained from you as a result of your participation in this study.

If you give us your permission by signing this document, we plan to use data obtained from your responses to the group session questions, and data from your completed questionnaires, for analysis and presentation in a doctoral thesis, it will also be published in local and international journal articles and conference presentations. In any publication, information will be provided in such a way that you cannot be identified.

Complaints may be directed to the Ethics Secretariat, The University of New South Wales, SYDNEY 2052 AUSTRALIA (phone 9385 4234, fax 9385 6648, email ethics.sec@unsw.edu.au). Any complaint you make will be investigated promptly and you will be informed of the outcome.

Feedback regarding the study's findings may be made available through the School of Risk and Safety Sciences' website at www.srss.unsw.edu.au, and through dance and human movement-related publications, including journal articles, magazines, newsletters, and conference presentations and proceedings.

Your decision whether or not to participate will not prejudice your future relations with the University of New South Wales. If you decide to participate, you are free to withdraw your consent and to discontinue participation at any time without prejudice.

If you have any questions, please feel free to ask us. If you have any additional questions later, Rachel Ward (Phone: 0419 273 454; Email: rachel.ward@unsw.edu.au) will be happy to answer them.

You will be given a copy of this form to keep.

Appendix L continued:

THE UNIVERSITY OF
NEW SOUTH WALES

School of Risk and Safety Sciences
School of English, Media & Performing Arts
Approval Number: 08/2010/59

BIOMECHANICAL INVESTIGATION OF THE ACCURACY OF VISUAL OBSERVATION AND EFFICACY OF INSTRUCTION IN CLASSICAL BALLET TEACHING

PARTICIPANT CONSENT FORM

I,

....
[Please PRINT full name]

have read and understood the Information for Participants on the above named research.

I have been made aware of the procedures involved in the study, including any known or expected inconvenience, risk, discomfort or potential side effects and of their implications as far as they are currently known by the researchers.

I freely choose to participate in this study and understand that I can withdraw at any time.

I also understand that the research study is strictly confidential, and agree that I will not disclose any information about participating dancers whose video images I observe.

I hereby agree to participate in this research study.

....
Signature of Participant

....
Date

Appendix M: Ballet Teacher Questionnaire

THE UNIVERSITY OF NEW SOUTH WALES

Teacher ID#: ______

School of Risk and Safety Sciences
School of English, Media & Performing Arts
Approval Number: 08/2010/59

BIOMECHANICAL INVESTIGATION OF THE ACCURACY OF VISUAL OBSERVATION AND EFFICACY OF VERBAL INSTRUCTION IN CLASSICAL BALLET TEACHING

BALLET TEACHER QUESTIONNAIRE

1. Date: ____________________ **2.** Date of Birth: ____________________

Your Dance Training History

3. Have you ever undertaken any formal training in classical ballet? (Yes / No)

4. If yes, at what age did you commence your formal classical ballet training?______ (years)

5. How many years of formal classical ballet training have you had?______ (years)

6. Have you successfully passed any ballet syllabus examinations? (Yes / No)

7. If yes, please specify the name of the ballet syllabus and highest level examination you have passed (e.g. Royal Academy of Dancing (RAD) Intermediate; Cecchetti Advanced 1)

____

____

8. At any time during your ballet training did you undertake full-time classical ballet training? (Yes/No)

9. How long did you undertake full-time classical ballet training?______ (years)

10. Do you still take classical ballet classes (Yes / No)

11. If yes, how many hours of classical ballet classes do you take per week?_________ (hours)

12. If you no longer take classical ballet classes, how long has it been since you stopped taking classical ballet classes?______ (years).

13. Do you currently take classes in or perform other styles of dance? (Yes / No)

Appendix M continued:

THE UNIVERSITY OF NEW SOUTH WALES

Teacher ID#: ______

14. If yes, please circle the other styles of dance that you currently do (circle as many as applicable)

- Jazz
- Tap
- Contemporary
- Ballroom
- Hip Hop
- Street Funk
- Salsa
- Other (please specify) ____________________

15. Which style do you currently spend most of your time doing? (please only circle one)

- Ballet
- Jazz
- Tap
- Contemporary
- Ballroom
- Hip Hop
- Street Funk
- Salsa
- Other (please specify) ____________________

16. How many hours do you spend doing this style of dance per week?______ (hours)

Your Dance Performance History

17. Are you currently working as a classical ballet dancer in a professional classical ballet company (Yes / No)

18. If no, have you ever worked as a professional ballet dancer in a professional classical ballet company (Yes / No)

19. How many years did you work /have you been working as a professional ballet dancer in a professional classical ballet company?______ (years).

20. What was/is the highest rank you have reached in a professional classical ballet company?

____

21. Have you worked as a professional dancer in any other styles of dance (e.g. contemporary dance, musical theatre, commercial dance) (Yes / No)

22. Please describe the styles of dance you have performed professionally and state the number of years you worked professionally in these styles.

____

____

____

____

Appendix M continued:

THE UNIVERSITY OF NEW SOUTH WALES

Teacher ID#: ______

Your Teacher Training History

23. Have you ever undertaken any formal training in classical ballet teaching? (Yes / No)

24. If yes, please list the school/course/institution/organisation where you took your teacher training.

____

____

____

25. What was the duration of your ballet teacher training course? _____ years, or _____ weeks

26. Was this course (please only circle one)
    - Full-time
    - Part-time

Your Teaching History

27. How long (if applicable) have you been a professional classical ballet teacher? ___ years

28. How many hours per week do you currently work as a professional classical ballet teacher? ______ hours

29. What is the age range of your ballet students (please circle all that apply)
    - Less than 5 years
    - 5 - 10 years
    - 11-15 years
    - 16 -18 years
    - Adult non-professional ballet dancers
    - Adult professional ballet dancers

30. Do you currently teach other forms of dance as well as classical ballet? (Yes/No)

31. If yes, please circle the other styles that you currently teach.
    - Jazz
    - Tap
    - Contemporary
    - Ballroom
    - Hip Hop
    - Street Funk
    - Salsa
    - Other (please specify) ________________

32. Which style do you currently spend most of your time teaching? (please only circle one)
    - Ballet
    - Jazz
    - Tap
    - Contemporary
    - Ballroom
    - Hip Hop
    - Street Funk
    - Salsa
    - Other (please specify) ________________

Appendix M continued:

THE UNIVERSITY OF NEW SOUTH WALES

Teacher ID#: ______

Your Anatomy Background

33. Have you ever undertaken any formal training in anatomy of the human body? (Yes / No)

34. If yes, please list the course/school/ institution/organisation where you took your anatomy training.

____

____

____

35. What was the duration of your anatomy course?______ years, or ______weeks

36. Was this course (please only circle one)
    - Full-time
    - Part-time

Your Biomechanics Background

37. Have you ever undertaken any formal training in biomechanics of the human body? (Yes /No)

38. If yes, please list the course/school/ institution/organisation where you took your biomechanics training

____

____

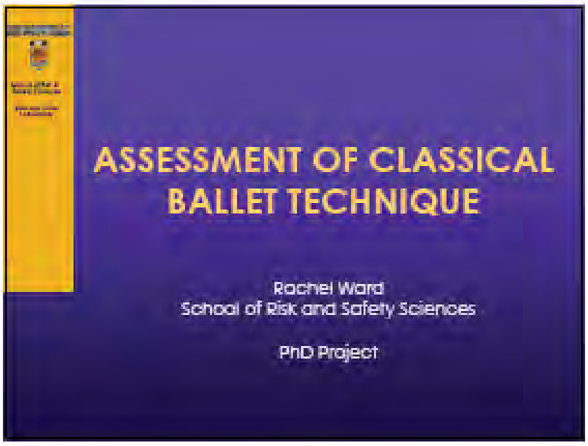
____

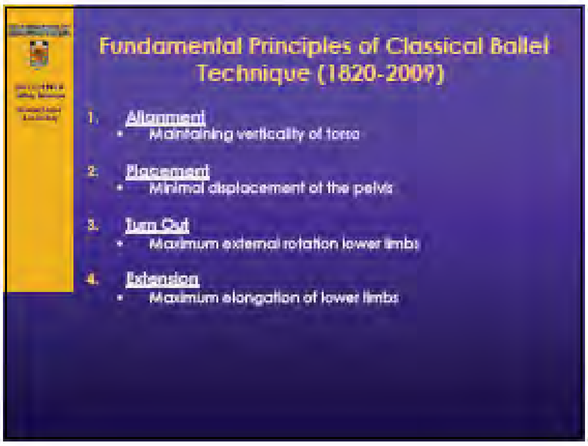
39. What was the duration of your biomechanics course?______ years, or ______weeks

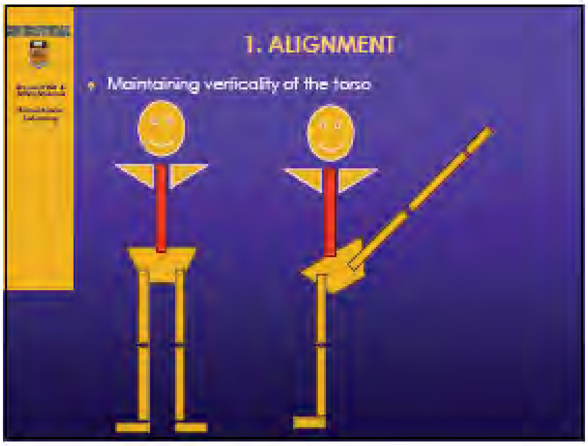
40. Was this course (please only circle one)
    - Full-time
    - Part-time

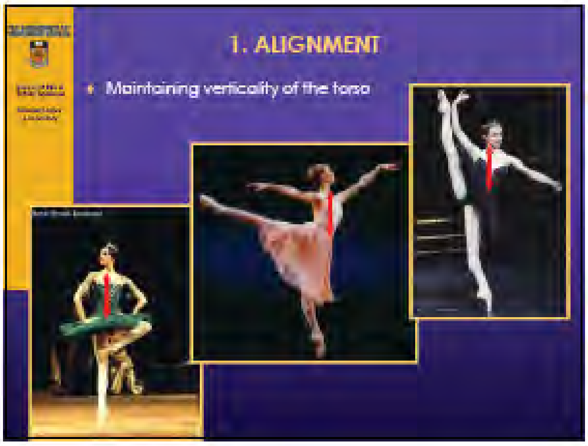
Thank you for completing this questionnaire.

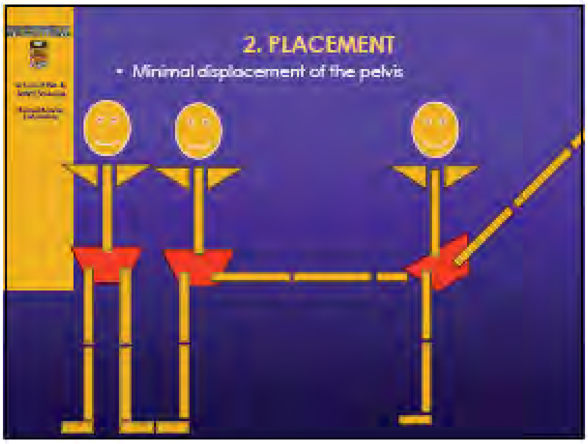
Appendix N: Qualitative Analysis Questionnaire – Introductory information and questions presented for Step 1 only. Same questions and format were repeated for Steps 2–5











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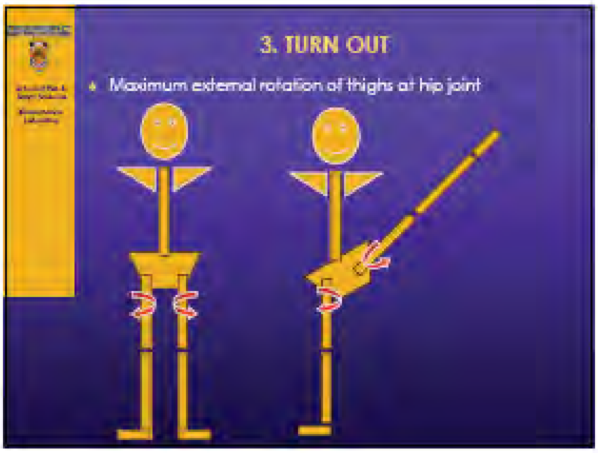

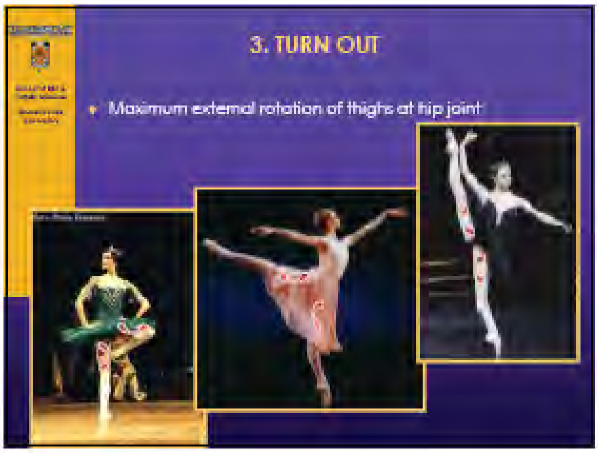

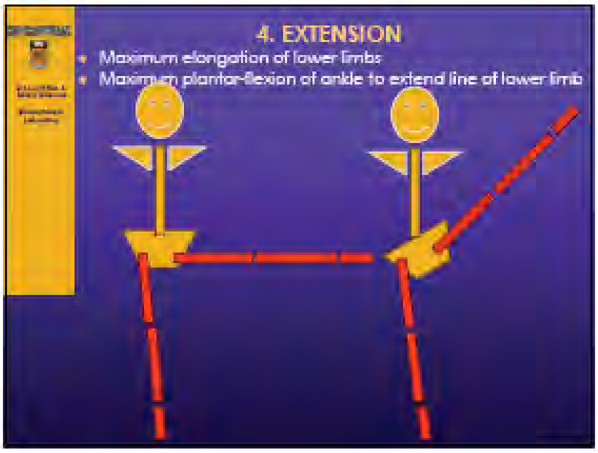

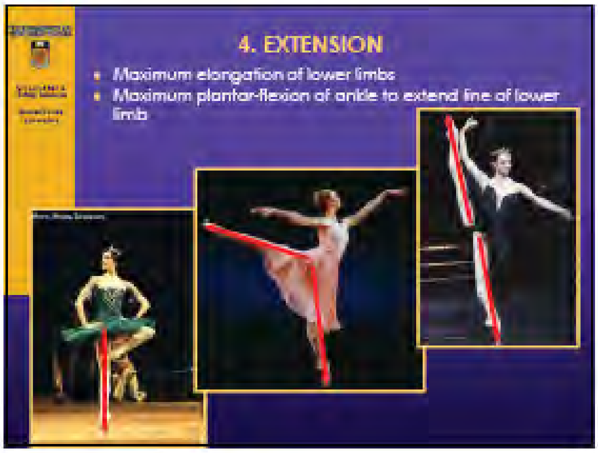

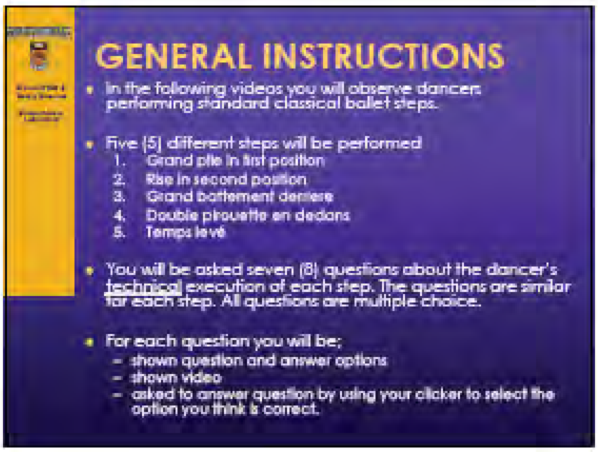

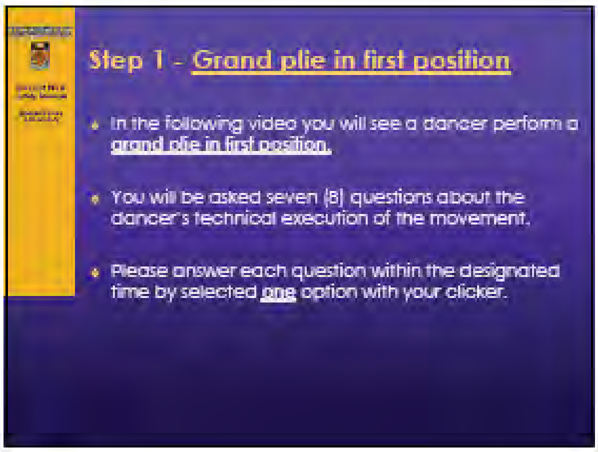

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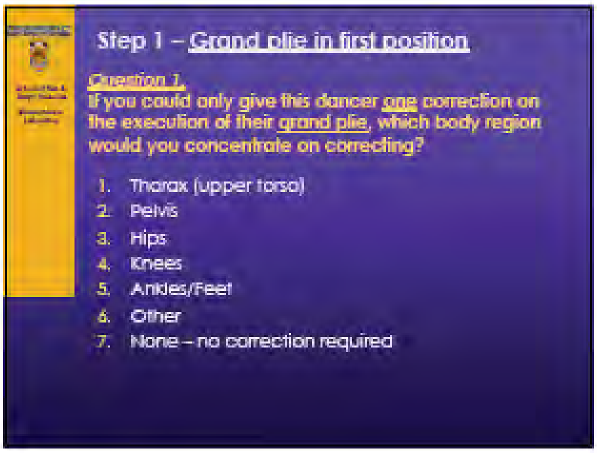

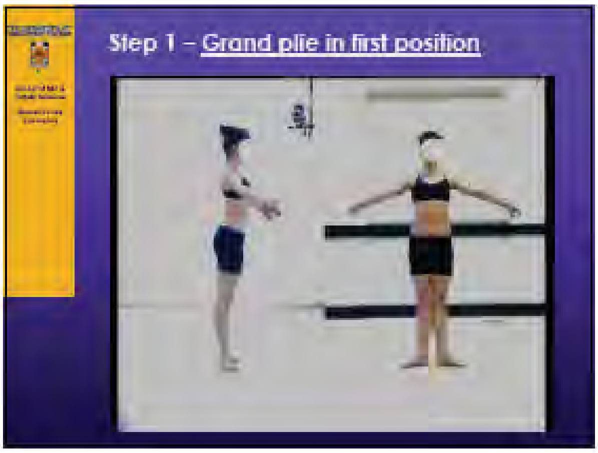

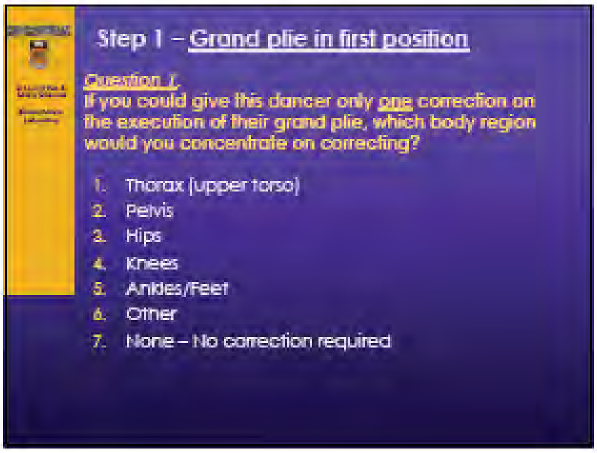

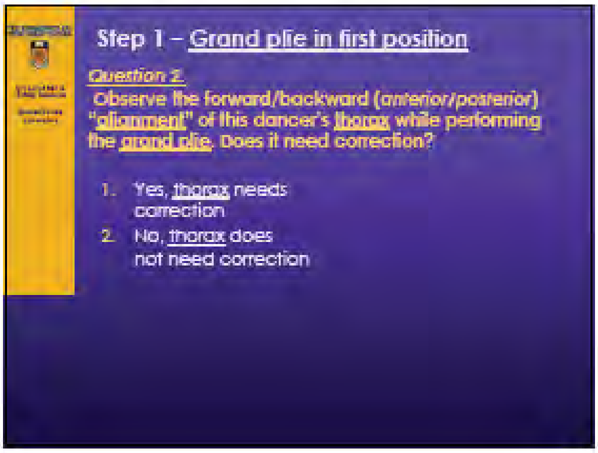

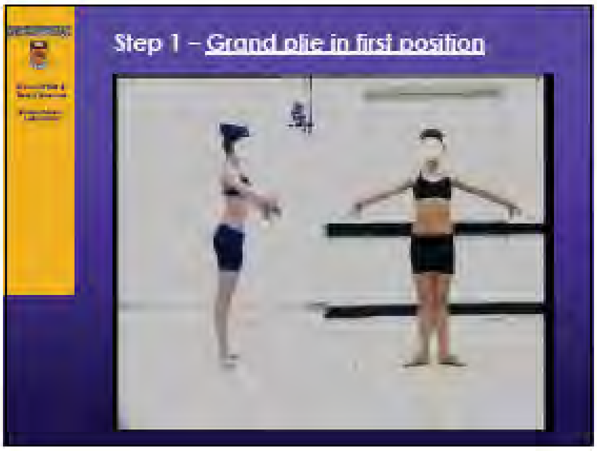

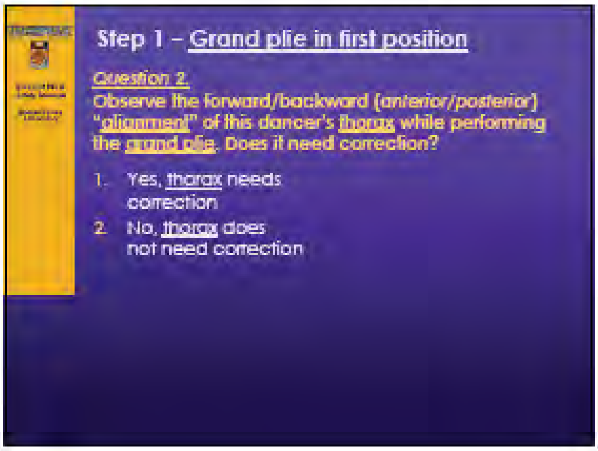

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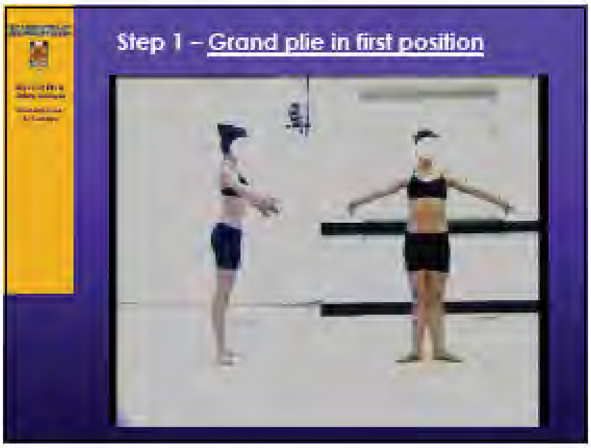

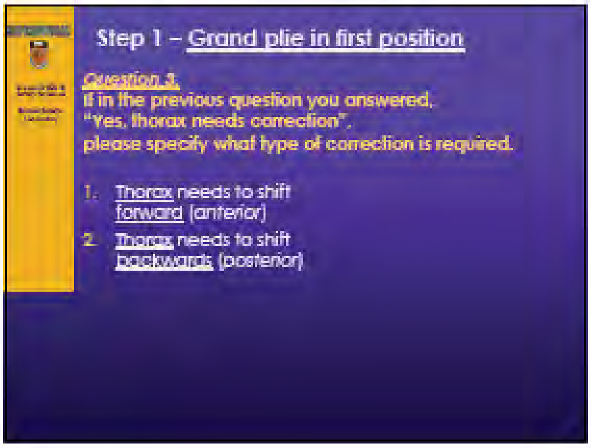

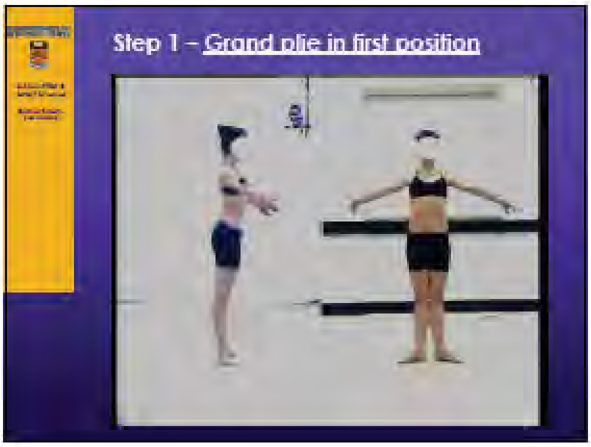

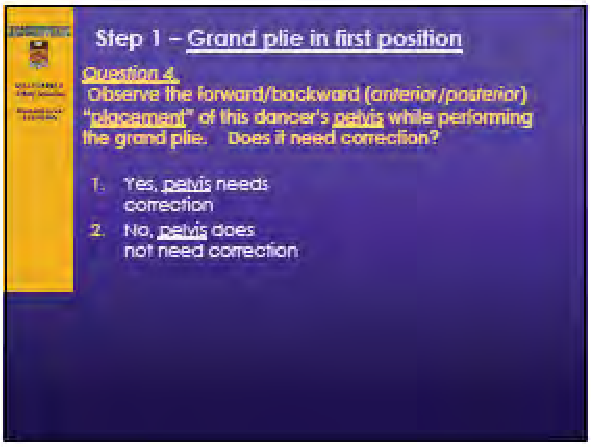

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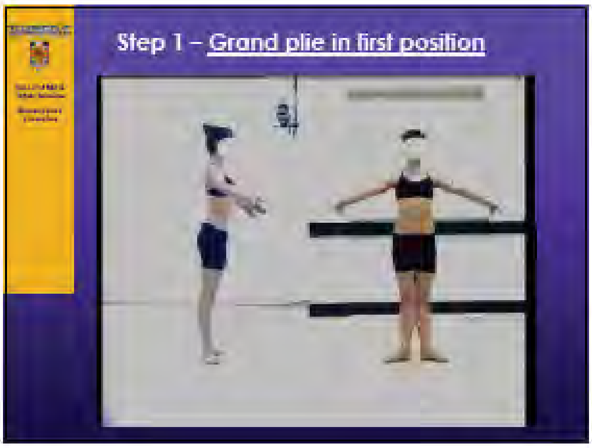

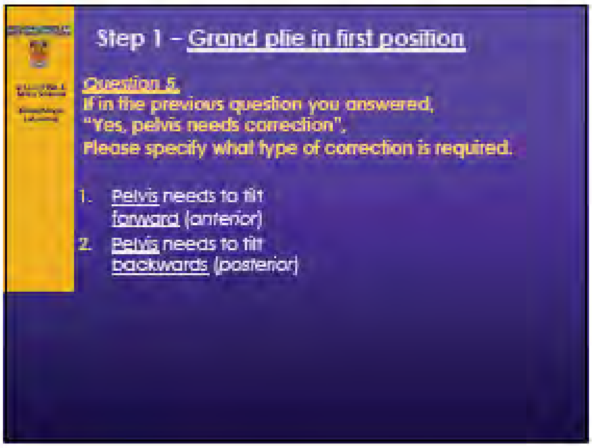

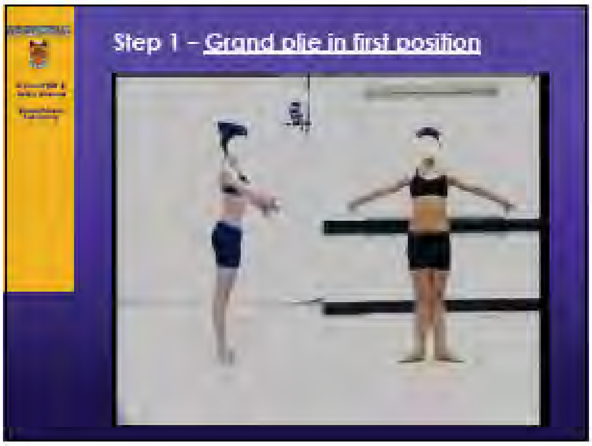

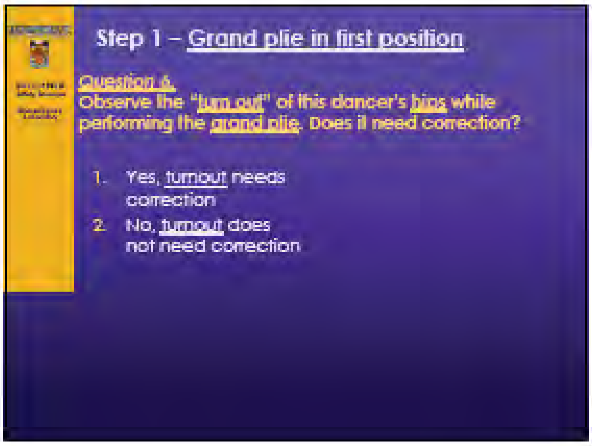

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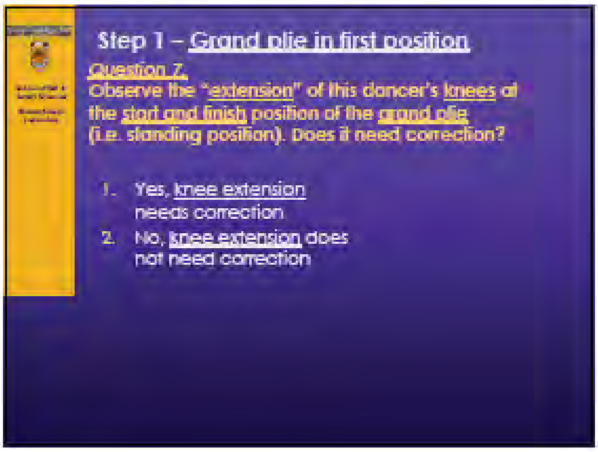

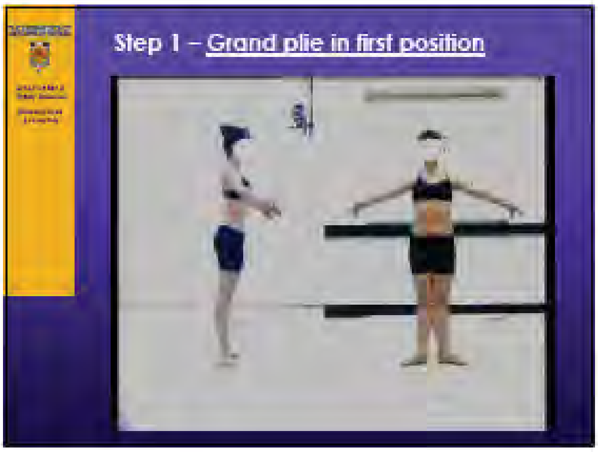

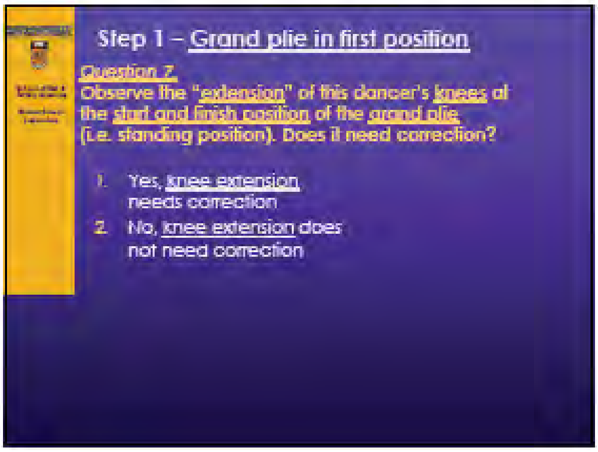

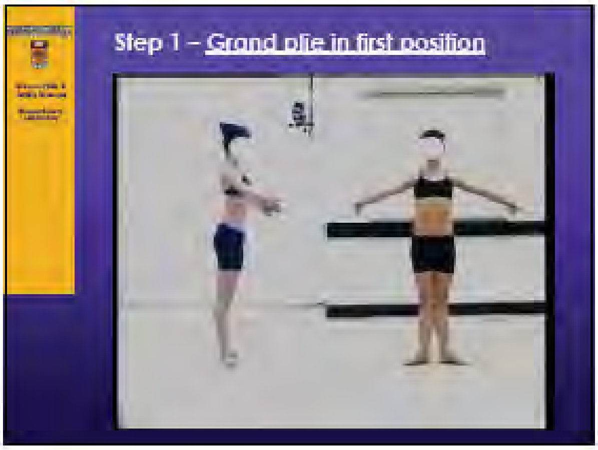

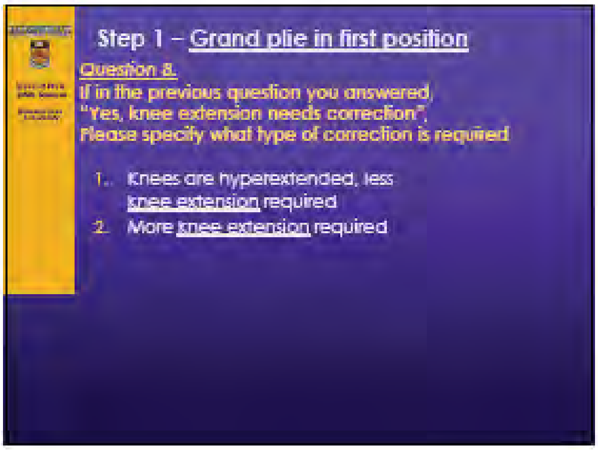

Appendix O: Chapter 4 - Percentages of Accurate Responses, Type I and Type II Errors

Teaching Experience: 0 years (N=12)

	Rated "Incorrect"	Rated "Correct"	Total
Correct Technique	15% (Type I Error)	30% (Accurate)	45%
Incorrect Technique	21% (Accurate)	34% (Type II Error)	55%
Total	36%	64%	100%

Teaching Experience: 1-9 years (N=11)

	Rated "Incorrect"	Rated "Correct"	Total
Correct Technique	17% (Type I Error)	28% (Accurate)	45%
Incorrect Technique	25% (Accurate)	30% (Type II Error)	55%
Total	42%	58%	100%

Teaching Experience: ≥10 years (N=10)

	Rated "Incorrect"	Rated "Correct"	Total
Correct Technique	21% (Type I Error)	24% (Accurate)	45%
Incorrect Technique	41% (Accurate)	14% (Type II Error)	55%
Total	62%	38%	100%

Appendix P: Chapter 5 - Correlation Matrix for Different Versions of Quantitative Assessment Tool

		14 Steps	7 Steps	4 Steps	3 Steps	4 Other Steps	3 Other Steps
14 Steps	Correlation Coefficient	1.000	0.908**	0.868**	0.851**	0.582*	0.385
	Sig. (2-tailed)		0.000	0.000	0.000	0.029	0.175
7 Steps	Correlation Coefficient	0.908**	1.000	0.903**	0.732**	0.503	0.389
	Sig. (2-tailed)	0.000		0.000	0.003	0.067	0.169
4 Steps	Correlation Coefficient	0.868**	0.903**	1.000	0.859**	0.644*	0.525
	Sig. (2-tailed)	0.000	0.000		0.000	0.013	0.054
3 Steps	Correlation Coefficient	0.851**	0.732*	0.859**	1.000	0.657*	0.415
	Sig. (2-tailed)	0.000	0.003	0.000		0.011	0.140
4 Other Steps	Correlation Coefficient	0.582*	0.503	0.644*	0.657*	1.000	0.851**
	Sig. (2-tailed)	0.029	0.067	0.013	0.011		0.000
3 Other Steps	Correlation Coefficient	0.385	0.389	0.525	0.415	0.851**	1.000
	Sig. (2-tailed)	0.175	0.169	0.054	0.140	0.000	

***Correlation is significant at the 0.01 level.*
**Correlation is significant at the 0.05 level.*