

Mapping the vestibular evoked myogenic potential (VEMP)

Author:

Colebatch, James

Publication details:

Journal of Vestibular Research

v. 22

Chapter No. 1

pp. 27-32

0957-4271 (ISSN)

Publication Date:

2012

Publisher DOI:

<http://dx.doi.org/10.3233/VES-2011-0438>

License:

<https://creativecommons.org/licenses/by-nc-nd/3.0/au/>

Link to license to see what you are allowed to do with this resource.

Downloaded from <http://hdl.handle.net/1959.4/53128> in <https://unsworks.unsw.edu.au> on 2024-04-20

Title: Mapping the vestibular evoked myogenic potential (VEMP)

Running title: Mapping the VEMP

Author: James G. Colebatch

Prince of Wales Clinical School , University of New South Wales and Neuroscience

Research Australia, Randwick, Sydney, NSW 2031, Australia.

Corresponding Author: Professor JG Colebatch
Institute of Neurological Sciences
Prince of Wales Hospital
Randwick,
NSW 2031
Australia
Phone +61 2 9382 2407
Fax +61 2 9382 2428
Email: j.colebatch@unsw.edu.au

Keywords: vestibular reflexes, vestibular evoked myogenic potential, mapping, VEMP

Acknowledgement: Dr Shaun Watson assisted in the data collection. This work was supported by the National Health and Medical Research Council of Australia.

Abstract

Effects of different electrode placements and indifferent electrodes were investigated for the vestibular evoked myogenic potential (VEMP) recorded from the sternocleidomastoid muscle (SCM). In 5 normal volunteers, the motor point of the left SCM was identified and an electrode placed there. A grid of 7 additional electrodes was laid out, along and across the SCM, based upon the location of the motor point. One reference electrode was placed over the sternoclavicular joint and another over C7. There were clear morphological changes with differing recording sites and for the two reference electrodes, but the earliest and largest responses were recorded from the motor point. The C7 reference affected the level of rectified EMG and was associated with an initial negativity in some electrodes. The latencies of the p13 potentials increased with distance from the motor point but the n23 latencies did not. Thus the p13 potential behaved as a travelling wave whereas the n23 behaved as a standing wave. The C7 reference may be contaminated by other evoked myogenic activity. Ideally recordings should be made with an active electrode over the motor point.

Introduction

The vestibular evoked myogenic potential (VEMP), recorded from the sternocleidomastoid muscles (SCM) has become a popular means of electrophysiological assessment of vestibular function (see [2,6] for reviews). The potential is generated by modulation of surface EMG evoked by a short period of inhibition of motor unit firing [4]. The optimum location for an active recording electrode is said to be the middle part of the SCM [7] or “near the motor point” [6]. Theoretically the motor point, corresponding to the innervation zone of the muscle, would be expected to have several advantages: the shortest latency (as the EMG begins at this site), the largest amplitude (minimal cancellation and dispersion) and a purely positive onset. This study was designed to test for these properties, but also tested whether the location of the reference electrode also influenced the findings. A more remote reference has the advantage of being more nearly electrically neutral but also is more likely to record responses originating more widely.

Methods

Five healthy male subjects, aged 30 – 43 were studied. The motor point was identified using low intensity current (1-2 mA, 0.3 ms duration) delivered through a unipolar electrode and was taken to be the location with the lowest threshold for evoking a detectable twitch of the SCM. The left SCM was studied in all cases. In 3 subjects the location of the motor point was measured relative to the sternoclavicular joint and mastoid process.

Vestibular evoked myogenic potentials (VEMPs or cVEMPs) were recorded in response to 0.1 ms clicks either 95 or 100 dB NHL (normal hearing level, equivalent to 140 – 145 dB peak SPL - sound pressure level) given to the left ear via a

headphone (Telephonics TDH 49). A total of 8 channels and recording sites were used, based upon the location of the motor point and the line of the SCM muscle. One electrode was placed on the motor point and one 3cm above it in the line of the SCM, two others below, each separated by 3 cm. Four other recording sites were placed 3 cm transverse to the muscle belly, two at the level of the motor point and two 3 cm either side of the electrode below (Fig 1).

Figure 1 near here

As shown in the figure, the electrodes were identified with respect to the motor point, using axes parallel to the muscle belly, and transverse to it, using units of 3 cm. Two reference electrode sites were used (for different runs) – one over the ipsilateral sternoclavicular joint and one over the C7 process, the latter chosen as a remote reference, more likely to be truly indifferent. A total of 512 trials were recorded at approximately 3/sec and all the individual trials were recorded, apart from one subject in whom only the averages were recorded. EMG was amplified (8 Hz – 1.6 kHz) and recorded using a 1401+ laboratory interface using a sampling rate of 5 kHz and SIGAVG software (CED Ltd, Cambridge UK). One set of recordings was made using each reference electrode site. Unrectified traces were recorded and rectified averages were calculated offline.

Grand averaged VEMPs were calculated for illustration purposes for each of the two references using all 5 subjects. Average values were calculated using measurements from the individual records, unless otherwise indicated. Values are given as mean +/- standard deviation. The initial positivity is termed “p13” and the following negativity “n23”. Corrected amplitudes were calculated by dividing the peak to peak amplitude by the prestimulus mean rectified EMG level [8]. Positive potentials at the active electrode are shown as downward deflections.

Statistical analysis.

The amplitudes and latencies for all 8 electrodes for both reference sites were analysed using a repeated measures ANOVA design using two within subject factors, namely electrode and reference (PASW statistics, version 18). Sphericity was assumed.

Results

Motor point location

It was possible to define a clear motor point in all the subjects and for all the threshold was < 2 mA. The location was 9-12.5 cm above the sternoclavicular joint, in the line of the muscle belly, corresponding to a mean of 63% (56-69%) of the distance between the sternoclavicular joint and the mastoid process.

VEMP properties: standard reference

VEMPs were recorded from all sites, but there were clear morphological changes with the different recording sites and the two references. Although results are given for averaged values, individual subjects showed similar findings (Fig. 2).

Figure 2 near here

For the standard reference (Table 1) the motor point (electrode 3) had on average the largest and earliest initial positivity (p13: $-50.6 \pm 22.8 \mu\text{V}$; 12.7 ± 0.9 ms), the largest peak-peak raw amplitude ($107.2 \pm 36.3 \mu\text{V}$) and the largest corrected amplitude (1.38 ± 0.50). The analysis of variance confirmed highly significant effects of electrode on p13 amplitude ($F_{7,28} = 7.77$, $P < 0.001$), n23 amplitude ($F_{7,28} = 4.02$, $P=0.004$) and peak to peak amplitude ($F_{7,28} = 5.26$, $P=0.001$). Mean rectified levels were also affected by electrode site ($F_{7,28} = 2.85$, $P=0.029$) and were largest for electrode 6 (for both references). Corrected amplitudes varied significantly with electrode, being highest for the motor point ($F_{7,28} = 4.08$, $P = 0.006$). Latency effects

of recording location differed for the two potentials: for the p13 latency there was a significant effect of electrode site ($P=0.003$) but not for the n23 potential. The grand average (Figure 2) demonstrates that all electrodes began with an initial positivity, with shortest latency at the motor point (7.6 ms) and longest latency at the most inferior electrode (9.2 ms).

Figures 3 and 4 near here

VEMP properties: C7 reference

For the C7 reference there were also differences for the different electrode locations and for the lower electrodes the morphology of the response differed, beginning with a negativity (Fig. 3). Like the standard reference, the motor point on average had the largest ($-47.7 \pm 22.0 \mu\text{V}$) and earliest ($11.9 \pm 1.68 \text{ ms}$) p13 response, the largest n23 response ($50.2 \pm 19.7 \mu\text{V}$) and peak to peak response ($97.9 \pm 41.0 \mu\text{V}$) and the highest corrected amplitude response (1.49 ± 0.62 ; Table 2). There was a trend for an effect on p13 amplitude (smaller for C7: $F_{1,4}=6.46$, $P=0.064$), highly significant effects of the reference on n23 amplitude (smaller for C7: $F_{1,4}=46.4$, $P=0.002$) and peak to peak amplitude (smaller for C7: $F_{1,4}=29.8$, $P=0.005$). The reference electrode had a significant effect on the mean rectified EMG ($F_{1,4}=14.9$, $P=0.031$), with smaller values at all electrodes for the C7 reference. There was no significant effect of reference electrode on p13 or n23 latency nor on corrected amplitude. In contrast to the standard recording site, several of the recording sites, but not the motor point, began with a small negativity, with similar onset latency in all electrodes (approximately of 6.6 ms). This peak was largest for electrode 8 (4.9 μV average, 9.4 ms latency).

There were significant interactions between electrode and reference, indicating that the effects were not uniform for the two references. These included highly

significant effects on: p13 latency ($F_{7,28}=3.63$, $P=0.007$); n23 amplitude (the motor points had similar amplitudes, the rest were smaller for C7, ($F_{7,28}=3.53$, $P=0.008$: Fig. 4) and significant effects for both p13 amplitude ($F_{7,28}=2.81$, $P=0.024$) and peak to peak amplitude ($F_{7,28}=3.25$, $P=0.012$).

Discussion

The location of the recording electrode has a significant influence upon the properties of the waveform recorded, an observation explicable in terms of the myogenic origin of the cervical VEMP response. The earliest and largest responses were recorded at the location of the motor point, and electrode location had significant effects on the amplitude of both the p13 and n23 potentials as well as the latency of p13. This is consistent with the potential effectively originating from the motor point and spreading out from it along the SCM with dispersion causing the reduction in amplitude. The motor point lay on average two thirds the way between the clavicular insertion of the SCM and its origin, so this should be the recommended location for the recording site for the VEMP, similar to current practice [7]. On the other hand, recording sites within 3 cm of the motor point give quite similar results. For the standard reference, electrodes located up to 3 cm away in any direction (electrodes 1, 2, 4 and 6) should cause on average a latency increase for p13 and n23 of at most 1 ms and a reduction in corrected amplitude of at most 21% (36% for raw amplitude – electrode 4: Fig. 4). The amplitude errors are less if the electrodes are placed along the line of the muscle belly (electrodes 1, 3 and 6: 12% for corrected amplitude and 19% for raw amplitude).

The latency of the initial positivity (p13) increased with distance from the motor point, while the latency of the negativity (n23) was unchanged. The increase in latency of the p13 wave might have been expected to reflect the speed of conduction

of the action potential for muscle. However, using the difference in latencies measured for the motor point and the most inferior electrode for both references gives estimates of over 15 m/s, which is higher than expected (4 m/s: [3]). A lower estimate is obtained when using the most inferior 3 cm only (approx 10 m/s), consistent with the innervation zone spreading beyond the motor point, but higher conduction velocities may also apply for larger diameter motor fibres [3]. The change in latency of p13 implies that this positivity is a travelling wave whereas the negativity is a standing wave. This difference in turn can be understood in terms of properties of the compound muscle action potential (CMAP). Colebatch and Rothwell [4] showed a brief period of inhibition of motor unit firing underlay the surface positive-negative wave of the VEMP and likened it to a “missing” or inverted CMAP. The CMAP has the opposite polarity – negative then positive - and for the CMAP the negativity acts as a travelling wave while the following positivity is generated by the action potential reaching the musculo-tendinous junction and therefore acts as a standing wave [5]. These properties have two consequences for the VEMP. Recording sites placed low in the neck may have spuriously delayed initial positivities whereas the timing of the following negativity (n23) is likely to depend upon the length of the SCM muscle fibres and thus upon neck length.

The usual reference site (the sternoclavicular junction) appears to be preferable to the C7 location. A remote recording location such as over the C7 vertebra should more closely approximate an ideal reference and the total background EMG activity detected using C7 was generally less than for the sternal reference, consistent with it being more electrically neutral. Activity recorded immediately beyond the muscle tendon, including the location of the conventional reference electrode, tends to be of the opposite polarity to that over the muscle itself [5],

meaning that the overall activity when using it as a reference will be increased. Interestingly, while the mean rectified was reduced overall by over 30% when using the C7 reference, there was no significant difference for the corrected amplitudes of corresponding responses. Corrected VEMP amplitudes have been proposed as a method of allowing for differences in background activity [8] and the observations indicate that this method removes some the variability introduced by using different references.

A further difference when using C7 was the presence of an initial negativity in several of the leads, maximal for the most inferior electrode. This initial negativity appeared in all the electrode recordings and also had a very short latency. Although the C7 reference was remote enough to be uninfluenced by SCM activity itself, it overlay the posterior neck muscles, the location of the “inion” response [1]. Our subjects were sitting up and it is unlikely that the posterior neck muscles were relaxed, so an inion response or response in other neck muscles [9] is possible. The inion response has an onset latency of approximately 6 ms [1], consistent with the latency noted in this study.

This study of the VEMP is consistent with its origin from modulated EMG activity in the SCM. The ideal location for the active electrode is over the motor point and deviations from this location will lead to increases in latency and decreases in amplitude. Fortunately these errors are small if the active electrode is placed within a few cm of the motor point. Remote references carry the risk of contamination by other myogenic activity. Finally, the positive and negative waves that make up the VEMP differ in that one behaves as a travelling wave, the other as a standing wave, differences that arise from their myogenic origin.

Table 1: Standard electrode reference

| Electrode | p13 Amp (uV) | p13 Lat (ms) | n23 Amp (uV) | n23 Lat (ms) | pp Amp (uV) | Rect (uV) ⁺ | Corr Amp ⁺ |
|----------------|--------------------|-----------------|--------------------|-----------------|----------------|---------------------------|--------------------------|
| 1 (0,3) | -38.2 | 13.7 | 48.3 | 24.0 | 86.5 | 67.5 | 1.27 |
| 2 (3,0) | -39.6 | 13.1 | 39.2 | 24.0 | 78.8 | 65.9 | 1.26 |
| 3 (0,0) | -50.6 | 12.7 | 56.7 | 23.6 | 107.2 | 77.6 | 1.38 |
| 4 (-3,0) | -29.9 | 13.2 | 39.1 | 24.0 | 69.0 | 67.8 | 1.09 |
| 5 (3,-3) | -31.6 | 13.0 | 51.0 | 23.7 | 82.6 | 76.1 | 1.21 |
| 6 (0,-3) | -30.3 | 13.7 | 59.4 | 23.9 | 89.6 | 82.6 | 1.21 |
| 7 (-3,-3) | -31.7 | 13.8 | 41.9 | 24.1 | 73.5 | 72.5 | 1.08 |
| 8 (0,-6) | -20.2 | 15.6 | 42.2 | 24.2 | 62.3 | 74.2 | 1.03 |
| Mean | -34.0 | 13.6 | 47.2 | 23.9 | 81.2 | 73.1 | 1.19 |

Electrode 3 is the motor point and the relative location of the other electrodes is indicated by their coordinates (in cm, see text). The data is the mean of 5 subjects, except for the rectified and corrected amplitude(⁺), which are the mean of 4. The findings for the motor point and the mean of the 8 values are shown bold. Rect = mean rectified EMG levels prior to the stimulus, Corr. Amp = corrected amplitude (peak to peak divided by mean rectified level).

Table 2: C7 reference electrode

| Electrode | p13 Amp (uV) | p13 Lat (ms) | n23 Amp (uV) | n23 Lat (ms) | pp Amp (uV) | Rect (uV) ⁺ | Corr Amp ⁺ |
|----------------|--------------------|-----------------|--------------------|-----------------|----------------|---------------------------|--------------------------|
| 1 (0,3) | -34.8 | 13.3 | 41.9 | 22.5 | 76.6 | 54.6 | 1.29 |
| 2 (3,0) | -29.0 | 12.1 | 24.4 | 22.3 | 53.4 | 39.6 | 1.32 |
| 3 (0,0) | -47.7 | 11.9 | 50.2 | 22.0 | 97.9 | 61.2 | 1.49 |
| 4 (-3,0) | -17.5 | 12.1 | 21.8 | 22.3 | 39.3 | 38.7 | 1.05 |
| 5 (3,-3) | -23.1 | 13.1 | 35.6 | 22.6 | 58.7 | 51.3 | 1.25 |
| 6 (0,-3) | -26.7 | 12.9 | 44.4 | 22.4 | 71.1 | 63.3 | 1.17 |
| 7 (-3,-3) | -18.6 | 12.7 | 24.3 | 22.5 | 42.9 | 45.6 | 0.95 |
| 8 (0,-6) | -15.5 | 15.9 | 24.7 | 24.2 | 40.3 | 51.2 | 0.85 |
| Mean | -26.6 | 13.0 | 33.4 | 22.6 | 60.0 | 50.7 | 1.17 |

Similar conventions as for Table 1. ⁺ mean of 4 subjects, remainder mean of 5.

References

- [1] R.G. Bickford, J.L. Jacobson and D.T.R. Cody, Nature of average evoked potentials to sound and other stimuli in man, *Ann NY Acad Sci* **112** (1964), 204-218.
- [2] K. Brantberg, Vestibular evoked myogenic potentials (VEMPs): usefulness in clinical neurotology, *Semin Neurol* **29(5)** (2009), 541-547.
- [3] F. Buchtal, C. Guld and P. Rosenfalk (1955), Innervation zone and propagation velocity in human muscle, *Acta Physiol Scand* **35** (1955), 174-190.
- [4] J.G. Colebatch and J.C. Rothwell, Motor unit excitability changes mediating vestibulocollic reflexes in the sternocleidomastoid muscle, *Clin Neurophysiol* **115(11)** (2004), 2567-2573.
- [5] Z.C.Lateva, K.C. McGill and C.G. Burgar, Anatomical and electrophysiological determinants of the human thenar compound muscle action potential, *Muscle Nerve* **19** (1996), 1457-1468.
- [6] S.M. Rosengren, M.S. Welgampola and J.G. Colebatch, Vestibular evoked myogenic potentials: Past present and future, *Clin Neurophysiol* **121** (2010), 636-651.
- [7] K. Sheykholeslami, T. Murofushi and K. Kaga, The effect of sternocleidomastoid electrode location on vestibular evoked myogenic potential, *Auris Nasus Larynx* **28** (2001), 41-43.
- [8] M.S. Welgampola and J.G. Colebatch, Vestibulocollic reflexes: normal values and the effects of age. *Clin Neurophysiol* **112** (2001), 1971-1979.
- [9] C.-H. Wu C, Y.-H. Young and T. Murofushi, Tone burst-evoked myogenic potentials in human neck flexor and extensor, *Acta Otolaryngol (Stockh)* **119** (1999), 741-744.

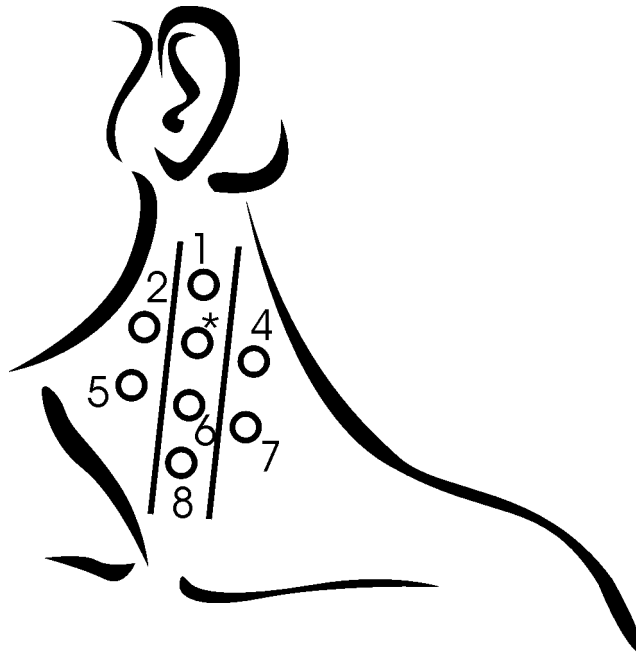


Figure 1. Diagram showing location of recording electrodes over the left SCM muscle, and the numbering convention. Electrode 3 (shown with the *) was placed over the location of the motor point as determined at the beginning of the experiment. Electrode 1 was placed 3 cm above, along the line of the SCM and electrodes 6 and 8 were placed 3 and 6 cm below electrode 3, along the line of the muscle belly. Electrodes 2 and 5 were placed 3 cm to the left of electrodes 3 and 6, perpendicular to the line of the muscle belly. Electrodes 4 and 7 were placed in similar positions to the right of electrodes 3 and 6.

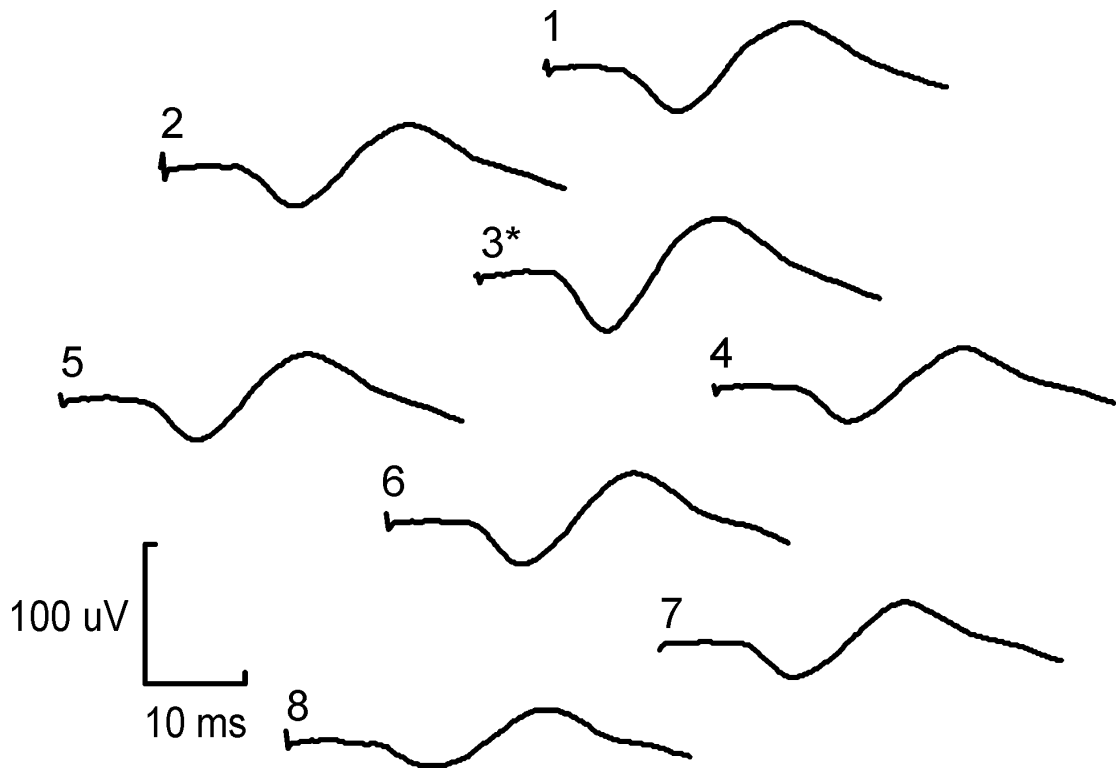


Figure 2. Grand averages of all 5 subjects, for each of the recording sites, using the sternoclavicular reference. The layout follows that of the recording sites shown in Figure 1, with the motor point (electrode 3) being marked with the *. The largest and earliest potential was recorded at electrode 3 (the motor point). The stimulus was given at the onset of the traces. Positive potentials at the active electrode gave downward deflections.

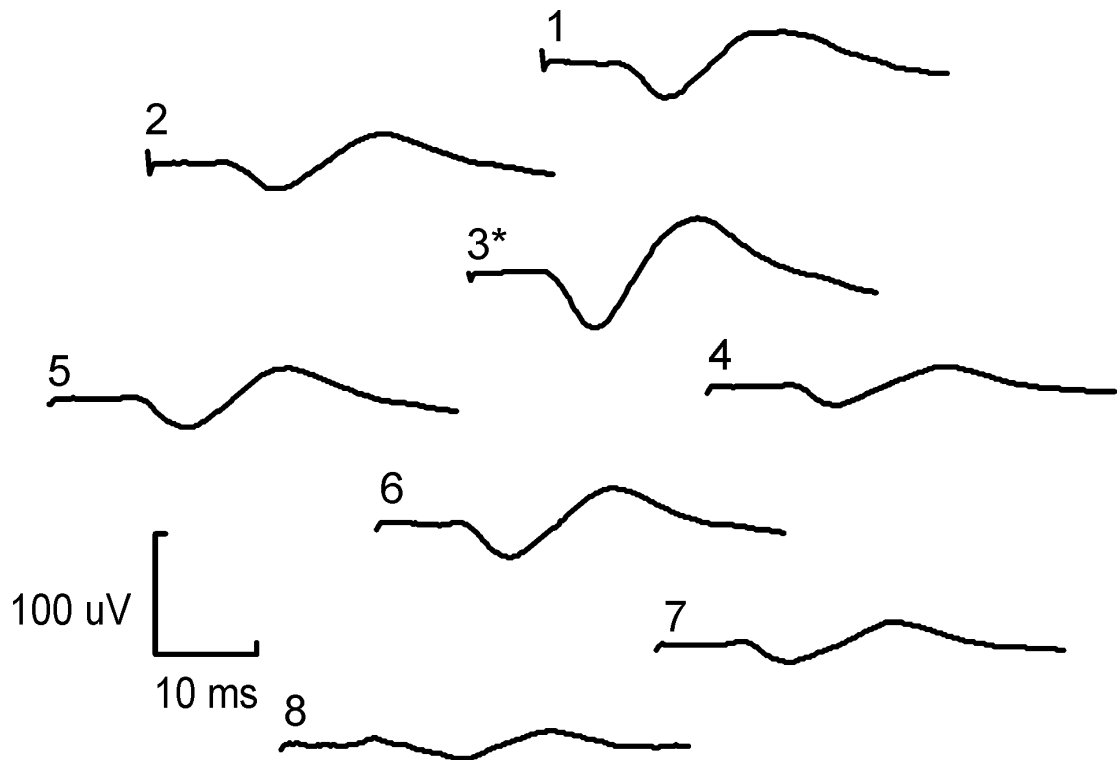


Figure 3. Grand averages of all 5 subjects, for each of the recording sites, using a reference over C7. The layout follows that of the recording sites shown in Figure 1, with the motor point (electrode 3) being marked with the *. The largest and earliest potential was again at electrode 3 (the motor point). All recording sites apart from the motor point begin with a small negativity, largest in electrode 8 (4.9 uV). The stimulus was given at the onset of the traces.

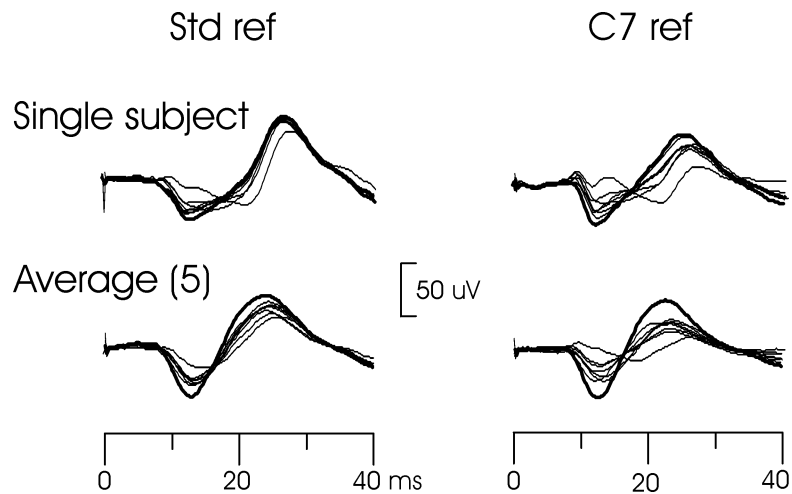


Figure 4. Superimposed traces from all 8 electrodes, with motor point response shown in the thick line. The upper part of the figure shows the results of one subject, the lower half the average for all 5 subjects. The left column shows the averages using the conventional reference, the right using C7. The latest response in all cases was recorded from electrode 8. A short initial negativity is evident for the C7 reference for the single subject. The motor point recording gives the largest response, but the difference from the other electrode sites is more marked for the C7 reference.