A PILOT STUDY TO INVESTIGATE THE EFFECTS OF TEST POSITION AND STIMULUS TYPE ON VESTIBULAR EVOKED MYOGENIC POTENTIALS

Capstone Project

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By

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ABSTRACT

Vestibular evoked myogenic potentials (VEMPs) are a non-invasive test of otolith function and a portion of the descending vestibulo-spinal system. Three subjects with normal function of the vestibular system underwent VEMP testing with 500 Hz tone bursts and click stimuli. Response characteristics were observed in both the sitting and supine test positions. The success rate of each stimulus in VEMP studies, the mean P1 and N1 latencies for both stimuli, the P1-N1 amplitude, the amplitude symmetry, and the relationship between muscle activation and P1-N1 amplitude were explored in each individual. The 500 Hz tone burst stimuli were more successful at evoking the desired response. Subjects generated more muscle activity as measured by EMG in the supine position than in the sitting position. Due to the small sample size, a clear relationship between muscle activation and amplitude did not emerge.

I dedicate this to my family.

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LIST OF ABBREVIATIONS

dBC	decibels C-weighted, characterizes intensity of short-duration sound
dBnHL	decibels referenced to normal hearing level
dBpeakSPL	decibels referenced to peak sound pressure level
dBSPL	decibels referenced to sound pressure level
EMG	electromyography, electromyogram
ENG/VNG	electronystagmography/videonystagmography
Hz	Hertz
kHz	kilohertz
µsec	microsecond(s)
µV	microvolt(s)
msec	millisecond(s)
SCM	sternocleidomastoid muscle
VEMP	vestibular evoked myogenic potential

CHAPTER 1

INTRODUCTION

The vestibular evoked myogenic potential (VEMP) is an acoustically-evoked muscle response generated by otolith activation. The saccule is the otolith responsible for transducing vertical movements of the head to the central nervous system. Because the saccule is located in the labyrinth beneath the stapes, sufficiently loud sound (105-125 dB peakSPL) can activate the saccule through stapedial vibration. The VEMP is a short-latency response recorded from surface electrodes placed over muscles of the neck, appearing as a series of two to four positive and negative peaks in the first 10-50 msec following the acoustic stimulus (Figure 1.1).

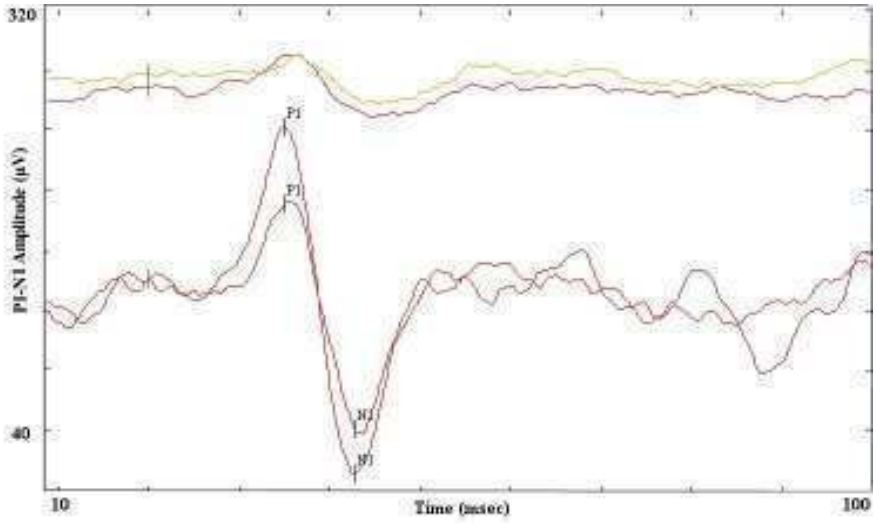

Figure 1.1 The VEMP is a muscular response evoked by sound. The first two peaks of the waveform, P1 and N1, have been identified here.

The value of VEMP testing is the selective assessment of the saccule and the integrity of its neurological connections through the inferior branch of the vestibular nerve (Colebatch, 2001). The VEMP is attractive in several regards: it offers a non-invasive test of otoliths, it assesses a branch of the vestibular nerve that caloric testing does not, the equipment needed to collect VEMPs would be familiar in labs equipped for other types of evoked potentials, and testing time is relatively brief and well tolerated by patients.

This study was designed to gain experience with VEMP testing using two kinds of stimuli and in two test positions. The experimental design resulted in four test conditions, which enabled a comparison of VEMP characteristics in each condition.

CHAPTER 2

REVIEW

2.1 HISTORICAL PERSPECTIVE

2.1.1 The Earliest Recordings

In 1964, Bickford, Jacobson, and Cody reported a short-latency "inion response" evoked by high intensity clicks. Their investigation was initiated to explore a possible cerebellar response to sound, recorded by previous investigators from an electrode situated over the inion (occipital bone projection at the base of the skull). Bickford and colleagues tested thirty normally-hearing subjects and four patients with cochleovestibular pathology. A recording electrode was placed at the inion and referenced to the mastoid. The subjects were tested while sitting. Activation of neck muscles was varied during the procedure by positioning the head in a forward or backward orientation. Muscle tension in the neck was created in the forward position with a head strap fixed to a pulley and weight system. Neck muscles were in a relaxed state during backward orientation. Acoustic clicks of 98-120 dBSPL were presented with earphones and characteristics of the response were observed. The resulting waveform was signal averaged and consisted of four peaks ranging in latency from 6-51 msec.

The study by Bickford, Jacobson, and Cody (1964) offered three observations: First, there was strong evidence that the inion response was myogenic, not cerebellar. The response was a recording of changes in the tonus of neck muscles near the inion. Second,

the amplitude of the waveform varied with the intensity of the sound stimulus. Loud clicks resulted in waveforms with large amplitudes; lower intensity clicks resulted in smaller amplitudes or sometimes the absence of the waveform's earliest deflections. Third, the response origin was localized to the vestibular system. The response was present in subjects with sensorineural deafness, but absent in those with lesions of the peripheral vestibular system. Despite the fact that the stimulus was acoustic, the response did not appear to be cochlear.

2.1.2 Evolving Understanding of the Response

Colebatch and Halmagyi (1992) resumed experimentation on the acoustically-evoked vestibular response in a case study documenting a patient before and after unilateral vestibular neurectomy with successful hearing preservation. An acoustically-evoked EMG response was present bilaterally before the surgical procedure. Following right-sided vestibular neurectomy, the response was absent on the right. This study is significant for two reasons: First, it supported previous research that localized the origin to the peripheral vestibular system. Second, these investigators used the sternocleidomastoid (SCM) muscles on the anterior surface of the neck as a recording site instead of the inion and obtained an acoustically-evoked vestibular potential similar in morphology and latency to previous studies. Subsequent investigators also using recording electrodes on the SCM confirmed that the response is dependent on the peripheral vestibular system and that vestibular pathology degrades or abolishes it (Colebatch et al., 1994; Akin & Murnane, 2001; Murofushi et al., 1999).

As understanding of the response developed and collection procedure evolved, the terminology changed from "inion response" to the more technically descriptive term "vestibular evoked myogenic potential," or VEMP.

In humans, the origin of the VEMP is often inferred non-invasively by studying patients with known lesions of the vestibular system. Basta et al. (2005a) approached the matter from a different perspective and directly stimulated the inferior vestibular nerve in several patients during otoneurosurgery. An EMG response was obtained from the sternocleidomastoid muscle ipsilateral to the side stimulated. Their work indicates that the inferior vestibular nerve is the initial branch of the reflex, and because the inferior branch is where saccular afferents are predominately located, it lends credence to a saccular origin.

2.2 ANATOMY AND PHYSIOLOGY

The anatomical pathway involved in vestibular evoked myogenic potentials bears several differences from those involved in a standard ENG/VNG test battery. Caloric testing accesses the vestibulo-ocular reflex by way of the horizontal semicircular canal. VEMP testing accesses parts of the vestibulo-spinal tract via the saccule. The reflex arc from the primary saccule afferents to the ipsilateral sternocleidomastoid muscle is a disynaptic pathway in experimental animals. Primary vestibular afferents emanating from the saccule project to the vestibular nuclei of the brainstem via the inferior vestibular nerve (McCue & Guinan, 1994; Murofushi et al., 1995; Murofushi & Curthoys, 1997). From the lateral and descending vestibular nuclei, the response travels along the ipsilateral vestibulospinal tract, to the spinal accessory nerve, and synapses on

the sternocleidomastoid (Murofushi et al., 1996; Kushiro et al., 1999; Uchino et al., 1997). The neuronal transmission time required to cross this two-neuron arc is in agreement with VEMP latencies reported clinically in humans (Murofushi et al., 1995) and implies that the course of the human vestibulocollic reflex arc is also a short, disynaptic pathway.

VEMP testing is typically conducted with acoustic stimuli presented by air conduction, meaning that VEMP testing relies on a healthy middle ear system to conduct the stimulus to the labyrinth. A conductive hearing loss can inhibit collection of VEMPs if the stimuli are presented by air conduction. Use of a bone oscillator is indicated in cases of conductive hearing loss and has been shown to produce a biphasic response with peak latencies comparable to air-conduction-evoked VEMPs (Basta et al., 2005b; Sheykholeslami et al., 2000). Bone conduction VEMPs do however have lower thresholds than would be expected from air conduction, leading to speculation that vibration of the skull recruits contributions from other structures, namely the utricle (Curthoys et al., 2006).

The VEMP is tapping into the vestibulocollic reflex. The vestibulocollic reflex works in tandem with the cervicocollic reflex to adjust and stabilize the head in space during whole body movements. Interaction between the vestibular system and neck muscles allows volitional adjustments that accurately oppose head displacements during body movement, thus maintaining clear vision on a chosen target (Guitton et al., 1986; Bronstein, 1988).

2.3 ELEMENTS IN THE COLLECTION PROTOCOL

2.3.1 Electromyography

Electromyography is a way to evaluate and record the electrical activity produced by muscle cells. The VEMP waveform is a signal averaged electromyogram. Surface electrodes are placed on the skin over the sternocleidomastoid muscle midway between the mastoid and the sternum. Placement at the midpoint demonstrates the highest VEMP amplitudes and the most consistent morphology (Sheykholeslami et al., 2001). These electrodes are referenced to an electrically neutral location.

2.3.2 Muscle Activation

The response can only be detected when the neck muscles are voluntarily activated. The VEMP is recording an IPSP (inhibitory post synaptic potential) on the cervical musculature and unless the muscles are contracted, there is no activity to inhibit. Methods used to activate the relevant musculature include turning the head to stretch the neck muscle or raising the head from a supine position to contract the neck muscles. The stretch activates the muscle unilaterally; raising the head activates both muscles simultaneously. Based on available literature, both poses are capable of creating effective activation of the SCM muscles for VEMP testing. Features of the VEMP are essentially the same between the two methods except for the amplitude, which may be larger when using the method of bilateral activation (Wang & Young, 2006; Versino et al., 2001).

2.3.3 Acoustic Stimuli

Clicks and 500 Hz tone bursts are regularly available on evoked potential units equipped to collect the auditory brainstem response. Clicks are brief pulses of broadband energy having a short duration (approximately 50-200 μsec) and an instantaneous onset.

Tone bursts are brief stimuli that contain energy within a discrete band of frequencies. Tone bursts are typically designed with a short-duration rise and fall time of a few milliseconds and no plateau (or a brief plateau).

The acoustic stimuli used to evoke VEMPs are frequently calibrated in decibels of normal hearing level (dBnHL), a unit that takes into account a normally-hearing person's perceptual (auditory) threshold for either click or tone burst stimuli. Because the VEMP is a vestibular response, it is acceptable to utilize a descriptive unit not referenced to the auditory system. Clicks and tone bursts are very short duration, only $1/1000^{th}$ or $5/100^{ths}$ of a second, respectively, and too brief to be calibrated in decibels of sound pressure level (dBSPL). However, a comparison can still be made by matching the peak sound pressure level of the click or tone burst to a sine wave having the same amplitude on an oscilloscope. The matching sine wave has a known sound pressure level and the corresponding acoustic transient can then be referenced in dB peakSPL. This unit reflects the physical peak voltage of the stimulus.

2.3.4 Stimulus Intensity

Click intensities of 95-100 dBnHL and 500 Hz tone burst intensities of 90-100 dBnHL are adequate to evoke a VEMP in normal individuals (Zhou & Cox, 2004; Welgampola & Colebatch, 2005). The presentation level necessary for other tone bursts

will vary with their center frequency, but in general, the level required becomes more intense as the center frequency rises (Akin et al., 2003).

2.3.5 Presentation Rate

The presentation rate is 5 clicks or tone bursts per second. Slower presentation rates do not dramatically improve the waveform morphology and quicker rates dampen the response amplitude (Wu & Murofushi, 1999).

2.3.6 Possible Risks

Click and tone burst stimuli used in VEMP testing are presented at a high intensity so the safety of the cochlea must be considered. The amount of damage possible from noise exposure increases with two variables: intensity of the acoustic stimulation and length of exposure time. Noise induced hearing loss often develops over time through repeated exposure to occupational and recreational noise sources. The exception to this scenario would be an incident of sufficient sound intensity to cause instantaneous hearing loss, either temporary or permanent. The American Academy of Audiology recognizes a level of 140 dBC peakSPL for impulsive sounds as hazardous for any length of exposure time (AAA, 2003). The intensity of the clicks and tone bursts used in VEMP studies are below this level, so the risk of permanent hearing loss is remote.

2.4 RESPONSE FEATURES

2.4.1 Waveform Morphology

The major landmarks of the waveform are discerned from the tracing based on polarity and absolute latency of its peaks or troughs, denoted P1 and N1. If a VEMP is present, other characteristics such as latency and amplitude can be measured. If a VEMP is absent, it provides meaningful information as well.

VEMPs are typically an ipsilateral response. Monaural acoustic stimulation usually evokes the myogenic response in the ipsilateral SCM, however sometimes a small-amplitude response of comparable latency is recorded from the contralateral side (Figure 2.2). Absence of the small contralateral component is not considered abnormal.

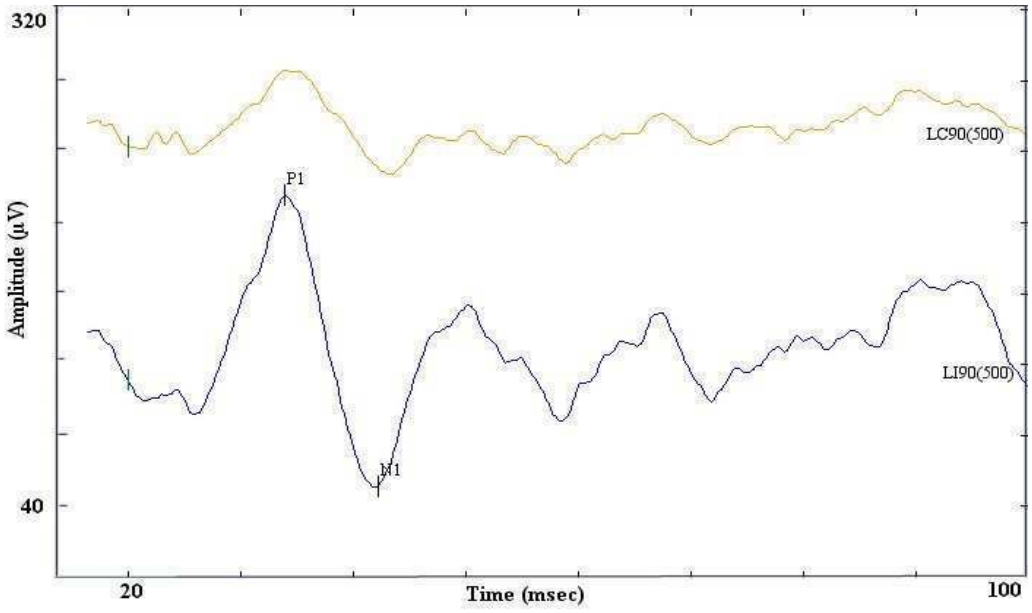

Figure 2.2 A response is visible in the contralateral recording (upper tracing). Results here were obtained in the supine position. (LI90(500)= left side of the neck, ipsilateral recording electrode, 90 dBnHL intensity, 500 Hz tone burst stimulus; LC90(500)= contralateral recording site)

There is a second biphasic waveform in the vestibular evoked myogenic potential, P2 and N2, occurring at approximately 34 and 44 msec respectively. There is evidence that this later component is not vestibular in origin (Colebatch et al., 1994) and its features are infrequently reported.

2.4.2 Absolute Latency of P1 and N1

Latency in VEMP studies is a measure of the vestibulocollic reflex's conduction time from the saccule and inferior vestibular nerve to the final motor endpoint. The diagnostic value of VEMP latency is limited, revealing little information about the function of the vestibular system specifically. Mostly, norms for the absolute latency of P1 and N1 are important for proper identification of the response. Knowing when the peaks should materialize facilitates proper identification of the waveform, which helps to discern the desired response from noise or artifact. The absolute latencies of P1 and N1 vary with the stimulus (Cheng et al., 2003; Akin et al., 2003), necessitating different norms for clicks and tone bursts. In general, P1 & N1 appear at 11-12 msec & 19-20 msec for clicks, and at 12-15 msec & 19-24 msec for 500 Hz tone bursts (Cheng et al., 2003; Welgampola & Colebatch, 2001; Akin et al., 2003).

A rare exception when latency may be clinically useful is in cases of large vestibular schwannomas, some of which could manifest in VEMP testing as a significantly delayed P1 and/or N1 latency (Murofushi et al., 2001). However, abnormal VEMP latency would probably never be used to diagnose a vestibular schwannoma, so again, the clinical utility of VEMP latency is mostly limited to the purpose stated above.

2.4.3 P1 – N1 Amplitude

The amplitude of the response is usually measured from the positive peak of P1 to the negative trough of N1. When it is abnormally low, amplitude is taken as a sign of dysfunction in the vestibular end organ. Because amplitude seems to assess the integrity of the saccule, pains have been taken to describe "normal" amplitude. There are however problems impeding the creation of norms for amplitude (described below), so it is difficult to define limits indicating abnormality. An alternative to creating norms for amplitude is to use a measure of amplitude symmetry, much the same way caloric testing uses one of a patient's ears as a reference for the other. Amplitude symmetry is reportedly quite good in normals (Akin et al., 2003; Ochi et al., 2001), so asymmetries are very useful for detecting abnormal VEMP amplitude.

Amplitude is difficult to norm because it varies with test factors such as stimulus intensity and stimulus frequency (for tone bursts) and it varies with patient factors like age and amount of muscle activation (Welgampola & Colebatch, 2005). Variability related to muscle activation can result in very large standard deviations if attempting to norm VEMP amplitude. If norms for amplitude are desired, two methods for reducing its range have been utilized and reported. One method is through monitoring and the other through a mathematical correction. The monitoring methods all use some sort of visual feedback to provide the patient with a way to maintain a relatively constant level of background EMG activity (Vanspauwen et al., 2006; Versino et al., 2001; Akin & Murnane, 2001). The mathematical method uses a "corrected" measure of amplitude: the peak-to-peak amplitude of the VEMP divided by the average EMG recorded in the 20

msec prestimulus intervals. This corrected amplitude yields a ratio value that could potentially minimize some individual differences.

2.4.4 Threshold

VEMP threshold is expected around 75-105 dBnHL for clicks (Colebatch et al., 1994; Akin et al., 2003; Ochi & Ohashi, 2003) and about 75-90 dBnHL for 500 Hz tone bursts (Akin et al., 2003).

Threshold of the VEMP is useful when it is abnormally low, a meaningful clinical sign of superior canal dehiscence (Brantberg et al., 1999; Minor, 2005).

2.4.5 Left/Right Symmetry

Amplitude and threshold are generally very symmetric when observed in a person with normal vestibular function (Ochi et al., 2001; Versino et al., 2001). If a significant asymmetry in threshold or amplitude is present, it suggests that dysfunction or hypofunction is likely present. The abnormal VEMP (i.e., absent response, atypically low amplitude, atypically low threshold) will be ipsiliateral to the lesioned ear. Because the VEMP has localizing power, describing symmetry is useful in the clinical setting.

Judging an asymmetry as significantly large is done by comparing a patient to normative data. For thresholds, there is evidence that symmetry is very high, with the left and right sides being within about 5 dB (Ochi et al., 2001).

Norms for amplitude symmetry are derived by plugging amplitude values from the left and right ears into the following: $|(L-R)|/(L+R)$. When using this formula, a significant asymmetry has been defined as one that exceeds two standard deviations from

the mean of a normal population, or about 0.35 (Young et al., 2002; Murofushi et al., 1999).

2.4.6 Tone Burst Tuning Curve

A tuning curve measures the intensity of an input necessary to evoke a desired response as a function of frequency. In the context of VEMPs, the tuning curve graphs the intensity of the different tone bursts that is necessary to produce a change in the firing pattern of the saccule neurons. VEMPs evoked by tone bursts between 250 – 3200 Hz reveal a broad, V-shaped tuning curve of the saccule having lowest threshold and highest amplitude between 250-750 Hz (McCue & Guinan, 1994; Murofushi et al., 1999; Todd et al., 2000; Akin et al., 2003; Rauch et al., 2004; Welgampola & Colebatch, 2001).

Due to the time required to construct a tuning curve for VEMPs, it is unlikely that one would be part of a standard collection protocol. However, it is interesting at least to note that the dynamics of the tuning curve appear to change in patients with endolymphatic hydrops. There is evidence that patients with endolymphatic hydrops either lose the specific sensitivity to stimuli between 250-750 Hz, or the tuning curve shifts to a higher frequency (Node et al., 2005; Rauch et al., 2004).

CHAPTER 3

METHODS

Three subjects participated in the experiment. None had any reported history of vertigo, hearing loss, dizziness, or any other cochleo-vestibular symptoms and normal vestibular function was assumed. Each subject was analyzed separately for their average EMG activity at the recording site, peak to peak VEMP amplitude, absolute latencies of P1 and N1, symmetry of EMG activity, and symmetry of P1-N1 amplitude. All were tested in supine and sitting positions and all underwent VEMP testing with clicks and 500 Hz tone bursts. Table 3.1 shows a grid outlining the basic format of the experiment.

	500 Hz tone burst	click
Sitting		
Supine		

Table 3.1 The four test conditions included in the study

The skin over all electrode locations was prepared using a skin peeling gel. The electrodes used were disposable dry gel electrodes. The non-inverting electrodes were placed symmetrically over the mid portion of the left and right sternocleidomastoid

muscles, the inverting electrode was placed on the upper sternum and the ground was placed on the forehead. An additional electrode was placed immediately inferior to each non-inverting electrode for the purpose of recording and averaging muscle activity (EMG) during testing.

A 2-channel evoked potential unit (ICS Chartr EP 200) was used to record surface electromyographic activity and to generate rarefaction clicks (97 dBnHL; 0.1 msec) and 500 Hz tone bursts (90 dBnHL; Blackman gated; rise/fall time, 2 msec; no plateau). Stimuli were presented to the subject via ER-3A insert earphones. Repetition rate was 5.1 clicks or tone bursts per second. The response was filtered (1-5 kHz) and amplified (5000x). A 20 msec delay preceded presentation of each stimulus; the recording window totaled 100 msec in duration. One hundred fifty presentations of the stimulus were signal averaged into a single representative waveform and graphed on a plot of time (msec) vs. amplitude (μV). At least two trials were attempted in each test condition. A value for EMG was generated by the software after each sequence of 150 presentations, which was indicative of the overall average electromyographic activity of the 150 recording windows. The order in which the two stimuli were used was random.

Muscle activation was achieved in two ways. In the supine position, the subject was reclined in an adjustable chair and asked to raise the head against gravity while turning the head to stretch the muscle ipsilateral to the test ear. In the sitting position, the subject was instructed to keep their shoulders against the chair and turn the head to stretch the neck muscle ipsilateral to the test ear. The order in which the positions were tested was random.

A response was judged "present" when a biphasic waveform appeared with the first positive peak occurring at approximately 10-15 msec, followed by a negative peak at approximately 19-25 msec. The absolute latencies of P1 and N1 were marked, P1-N1 amplitude was calculated by the software, and the mean level of EMG was noted. A response was judged "absent" when nothing beyond the background EMG activity could be discerned from the tracing.

Each subject was analyzed separately. Comparative within-subject analysis of VEMPs was accomplished by two-tailed independent samples t-tests and correlation. A significant difference indicates $p<.05$. All statistical analysis was completed using the commercial software program SPSS (version 17.0).

CHAPTER 4

RESULTS & DISCUSSION

4.1 RESULTS

4.1.1 Response Rate

The response rate indicates what percentage of the attempted trials resulted successfully in eliciting the desired response. For tone bursts, the response rate was 100% for all three subjects in sitting and supine positions. The response rate for clicks ranged from 0-75% and was 43% overall (Table 4.1).

Response Rate (with clicks)		
Subject	**Sitting**	**Supine**
1	1/2	2/5
2	2/4	2/4
3	0/4	3/4

Table 4.1 The number of successful trials when using click stimuli
Response rate for clicks was 43% overall. Independent samples t-tests indicate Subject 3 was the only to have significantly different EMG levels in trials with no response; in the sitting position, the mean EMG activity was higher in trials without a clear response.

The response rate seen here is low compared to other studies using clicks as stimuli in both sitting and supine positions (Table 4.2).

Reference	Presentation level	Test position	Response rate
Akin, Munane, & Proffitt (2003)	95 dBnHL	sitting	35/38 trials
Brantberg & Fransson (2001)	100 dBnHL	supine	46/46 trials
Cheng, Huang, & Young (2003)	95 dBnHL	supine	57/58 trials
Ochi, Ohashi, & Nishino (2001)	100 dBnHL	sitting	36/36 trials
Wu & Murofushi (1999)	95 dBnHL	supine	24/24 trials

Table 4.2 Response rate reported in other studies using click stimuli

4.1.2 Effects of Position

All three subjects demonstrated significantly higher average levels of EMG (muscle activation) when tested in the supine positions as opposed to the sitting position, $t(11)=-2.45$ for subject 1; $t(10)=-6.71$ for subject 2; $t(8)=-4.01$ for subject 3. Figure 4.1 illustrates the median and range of the EMG recorded in the two test positions. Means and standard deviations are shown in Table 4.3. Subject 1 initially had an outlier in the sitting position that was influencing the statistical analysis of EMG; when that case was excluded from the analysis, EMG between the two positions went from being equivalent to being significantly different.

Average electromyographic activity recorded in the two test positions

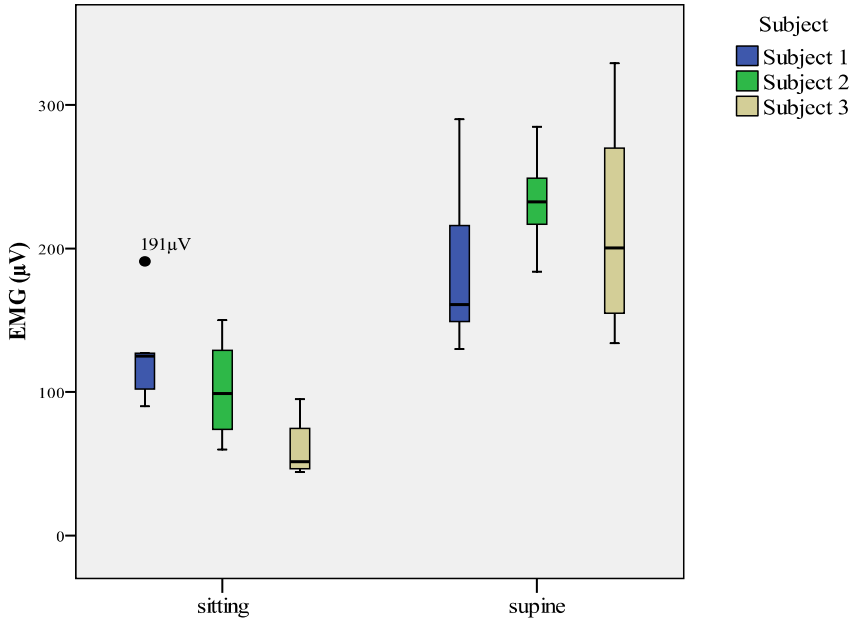

Figure 4.1 Medians, quartiles, and range for the EMG (muscle activity) recorded in the two test positions are presented. The average EMG activity recorded from the SCM during VEMP testing was different in the sitting and supine positions for Subject 2 and Subject 3, with supine position tending towards significantly higher levels of muscle activity. When the outlier of 191 µV was excluded from the data of Subject 1, EMG became significantly different between positions for that subject as well.

	Position	N (trials)	Mean (µV)	SD (µV)	Minimum (µV)	Maximum (µV)
Subject 1	sitting	4	111.00	18.02	90	127
	supine	9	189.22	61.33	130	290
Subject 2	sitting	6	101.83	33.68	60	150
	supine	6	233.33	34.17	184	285
Subject 3	sitting	4	60.50	23.36	44	95
	supine	6	214.83	73.14	134	329

Table 4.3 Average EMG activity and range for each subject in the two test positions

When stimulus types were pooled and amplitude analyzed purely by test position, Subjects 2 and Subject 3 demonstrated a significantly higher VEMP amplitude when in the supine position, $t(10)=-2.44$, $p<.05$ for Subject 2; $t(8)=-2.34$, $p<.05$ for Subject 3. For Subject 1, the peak to peak amplitudes in sitting (M=105.7 μV) and supine position (M=100.4 μV) were not significantly different (p=.769). When the case for Subject 3 containing the outlier was included, the difference remained insignificant (p=.376). Table 4.4 presents means and standard deviations for amplitude of Subjects 1-3.

Subject	Position	Stimulus	N (trials)	Mean (μV)	SD (μV)	Min (μV)	Max (μV)
1	sitting	tone burst	4	114.07	42.53	70.07	160.16
		click	1	126.71		126.71	126.71
	supine	tone burst	4	112.67	27.41	86.91	137.45
		click	5	90.53	27.84	53.71	123.29
2	sitting	tone burst	4	120.85	85.88	45.17	228.03
		click	2	95.82	32.97	72.51	119.14
	supine	tone burst	4	252.13	83.21	177.49	353.03
		click	2	154.05	3.80	151.37	156.74
3	sitting	tone burst	4	63.05*	25.36	42.97	96.44
		click	0				
	supine	tone burst	4	272.09*	64.51	215.09	332.03
		click	2	68.48	9.49	61.77	75.19

* denotes pairwise comparisons indicate a significant difference in amplitude at the .05 level

Table 4.4 Means and standard deviations for P1-N1 amplitude in the four test conditions

Independent samples t-tests of average EMG (muscle activity) in trials with and without VEMPs were not statistically different for any of the three subjects in the supine position, or for Subject 1 or Subject 2 in the sitting position ($p>.05$). Subject 3 did have significantly different levels of background EMG in successful ($M=60.5\ \mu V$) and unsuccessful ($M=103.0\ \mu V$) trials when in the sitting position.

4.1.3 Effect of Stimulus

In the previous section, stimulus types were pooled and amplitude was viewed in the context of test position. The stimulus types were also separated from each other and amplitude was again compared by position, e.g., click-evoked or tone-burst-evoked VEMP amplitude compared in sitting and supine positions. The peak to peak amplitudes were found to be statistically similar in Subject 1 and Subject 2 in both test positions (independent samples t-tests, $p>.05$). For Subject 3, the stimulus did have a significant effect on the peak to peak amplitude of the response when in the supine position, $t(4)=4.19$, $p<.05$, which is denoted in Table 4.4. Subject 3 was the only subject to show a significantly different peak to peak amplitude based on the stimulus used, with tone bursts tending toward a higher VEMP amplitude than clicks. The finding of larger amplitudes being evoked by tone bursts has been reported before in studies also using both types of stimuli, in the sitting position (Murofushi et al., 1999) and in the supine position (Akin et al., 2003).

4.1.4 Effect of background EMG

Previous investigators have reported a correlation between amplitude of the response and the level of background EMG present during testing (e.g., Lim et al., 1995; Colebatch et al., 1994), indicating that increased levels of EMG (muscle activity) result in increased amplitude of the VEMP. The correlation between average EMG and peak to peak amplitude was explored in every subject but did not reveal a strong or consistent relationship ($p>.05$, two tails). Figures 4.2 – 4.4 illustrate the various relationships between the mean EMG activity and VEMP amplitude that were found in Subjects 1-3 when explored via linear regression. Correlation coefficients, analysis of regression results and p-levels are presented with the regression lines in Figures 4.2 – 4.4 when applicable.

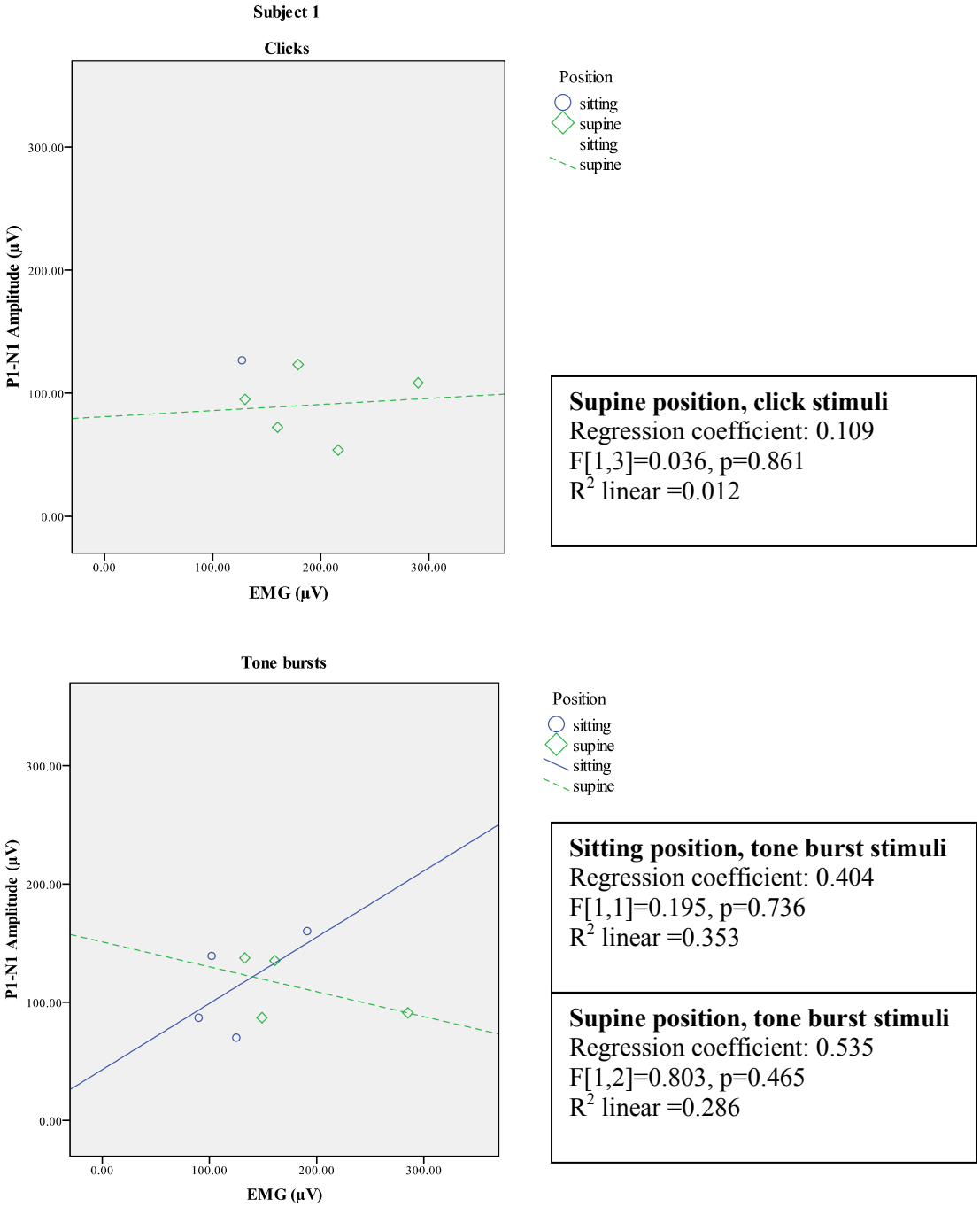

Figure 4.2 Relationship between mean EMG activity and VEMP amplitude for Subject 1.

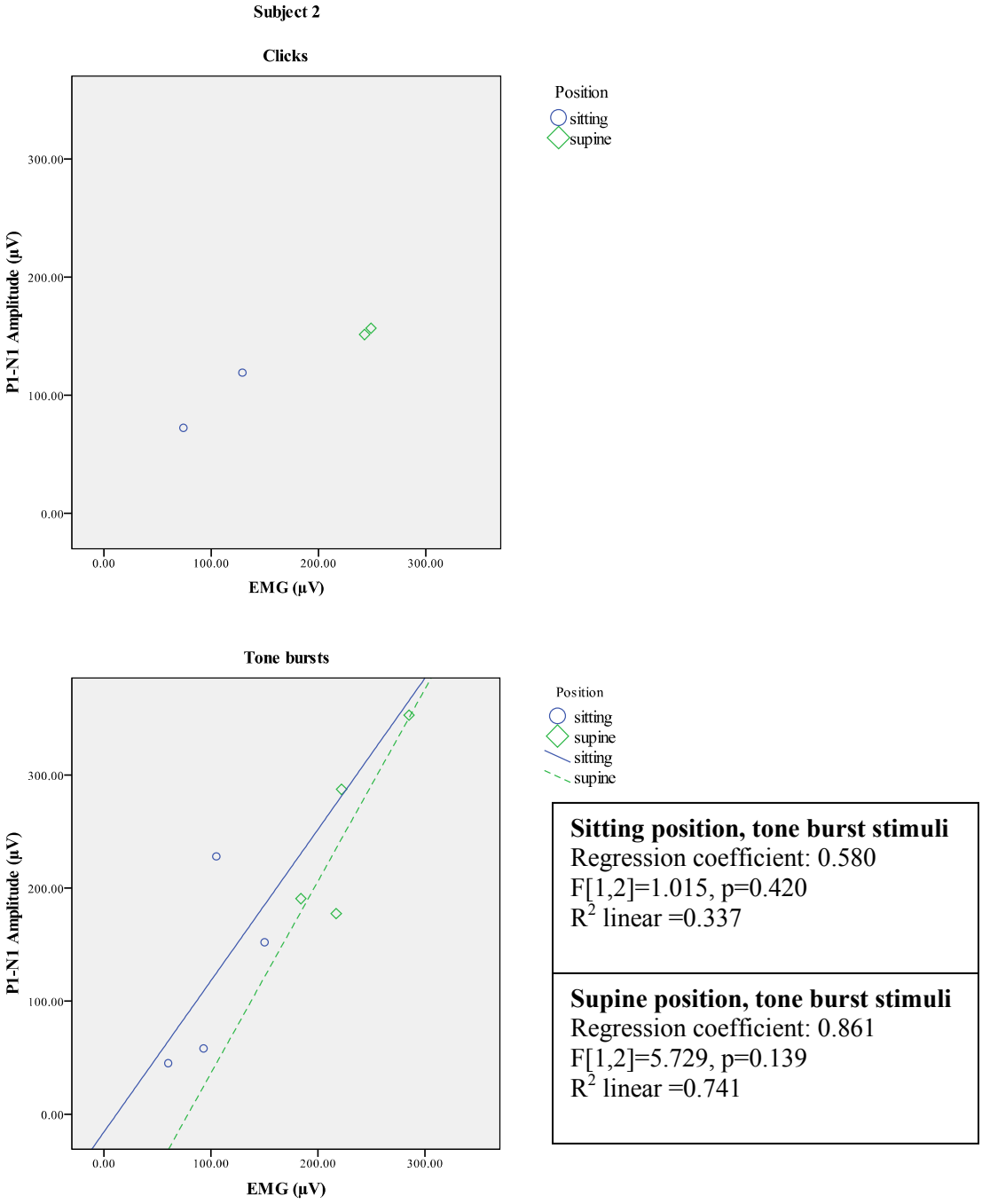

Figure 4.3 Relationship between mean EMG activity and VEMP amplitude for Subject 2.

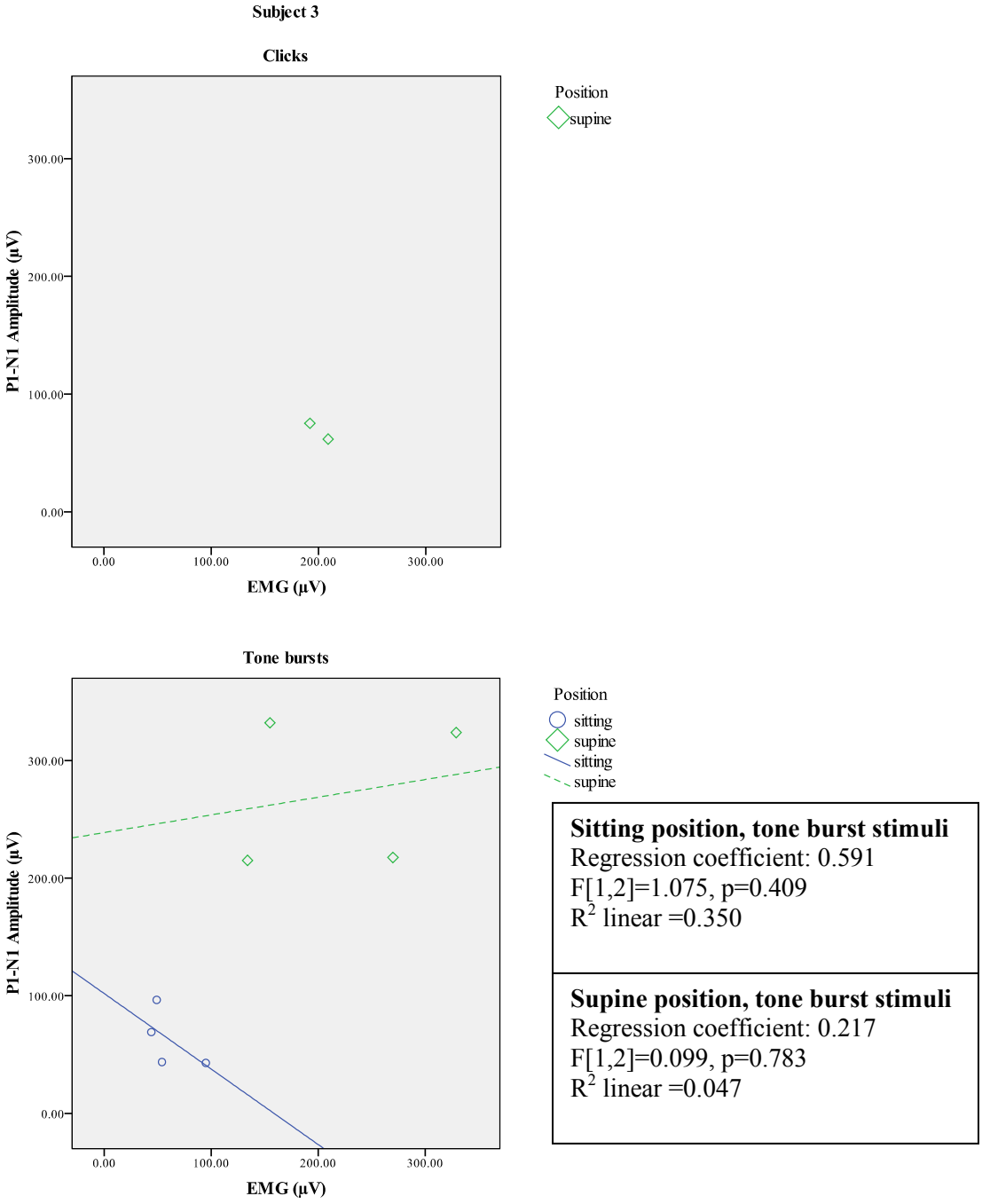

Figure 4.4 Relationship between mean EMG activity and VEMP amplitude for Subject 3.

4.1.5 Symmetry

The average EMG produced by the left and right sides of each subject was examined via independent samples t-tests. All subjects produced symmetric levels of muscular activity in the supine position. Subject 1 and Subject 3 were also symmetric in the sitting position; Subject 2 did show significantly asymmetric electromyographic activity in the right (M= 128 μV) and left (M= 75.7 μV) recording sites while in the sitting position, $t(4)=3.24$, $p<.05$.

Symmetry ratios for amplitude were calculated using the equation $|L-R| / L+R$, where L and R denote the grand averages of peak to peak amplitude of the successful trials from the left and right sides. Amplitude symmetry ranged from 0.01 to 0.60 (n=8, mean ± SD = .28 ± .22). The value 0.72 (mean + 2 SD) would be the upper limit of the normal range for the three subjects, which is higher than previous reports showing an upper limit of about 0.35 (Young et al., 2002; Murofushi et al., 1999).

All three subjects in the present experiment produced amplitude ratios below 0.35 in the supine position. Subject 1 and Subject 3 were also below 0.35 in the sitting position; amplitude ratio for Subject 2 in the sitting position exceeded this limit with a value of 0.57 for tone bursts and 0.60 for clicks. Recall that Subject 2 also had significantly asymmetric muscle activation in the sitting position.

4.1.6 Latency

Mean values for P1 and N1 latency are presented in Table 4.6. Independent samples t-tests indicate that absolute peak latencies were not affected by the test position ($p>.05$ for clicks and for tone bursts). Correlating latencies with background EMG did

not reveal any significant relationships ($p>.05$, two tails). In agreement with previous authors, mean P1 and N1 latencies were slightly different between clicks and tone bursts, statistically significant in some cases (denoted in Table 4.5).

		Tone burst		Click	
Subject		**P1 (msec)**	**N1 (msec)**	**P1 (msec)**	**N1 (msec)**
1	Mean	15.12*	22.23*	10.22*	17.56*
	Std. Deviation	.61	1.11	1.03	1.86
2	Mean	14.50	22.04	11.96	19.33
	Std. Deviation	1.33	1.26	2.19	2.02
3	Mean	15.65	24.35*	13.83	26.33*
	Std. Deviation	.82	1.45	2.59	.00
Total	Mean	15.09	22.87	11.40	19.61
	± 2 SD	2.08	3.26	4.18	7.28

*denotes pairwise comparisons of latency between stimuli were significantly different at the .05 level

Table 4.5 Average peak latencies and SD for clicks and tone bursts

4.2 DISCUSSION

The biggest problem encountered when reviewing the results of the present experiment was the small sample size. The results reported here are interpreted while mindful of this limitation.

The response rate observed in this experiment suggests that clicks were less successful at evoking VEMPs than the 500 Hz tone bursts. Clicks had a 43% success rate for evoking the desired response in this study, which is in contrast to the 100% success rate achieved with 500 Hz tone bursts. Initially, the low response rate was thought to be

a result of insufficient muscle activation during testing or possibly from a malfunction of the click generator. Inadequate muscle activation was ruled out after t-tests revealed no significant difference in the EMG levels in click-evoked trials with and without a response in two of the three subjects. A software malfunction was also reasoned to be less likely because clicks did in fact evoke VEMPs occasionally throughout the study. There was also no indication that the machine was poorly calibrated or the software out of date. For some unknown reason, the tone bursts were more successful as an evoking stimulus.

The lack of a clear and consistent relationship between EMG level and VEMP amplitude was notable. Electromyographic activity plays an essential role in VEMP testing since the response can not be detected from the SCM unless a background of muscle activity is present. The work of others who have investigated the relationship between varying degrees of muscle activation and subsequent VEMP amplitudes (e.g., Lim et al., 1995; Colebatch et al., 1994) indicate a positive covariation between these features. The obtained results were much more interesting and included at least two situations where increased EMG resulted in a decrease of VEMP amplitude. Correlation between EMG and amplitude never reached a level of significance and the regression analyses all had a high standard error of the estimate. In retrospect, more data points or a larger *n* may have reduced the observed variability. If an attempt had been made to create different levels of muscle activation during this study, a relationship between amplitude and muscle activation may have become more apparent.

It was decided that amplitude would be reported for each individual subject without any attempt to report a group mean or standard deviation. The variability of

VEMPs between subjects in this experiment has been observed to be high and it appears as though it will be difficult to describe a clinical feature such as amplitude with absolute values. More value was placed on symmetry of amplitude, comparing values obtained from the same physical body. However symmetry also showed some interesting variation, specifically with Subject 2, who produced different amounts of muscle activity from the two sides of the neck even though the physical act of turning the head one way or the other had no noticeable variation upon observation from the tester. A method for monitoring and maintaining muscle activation at a constant level has been described (e.g., Akin & Murnane, 2001). The use of monitoring may have prevented the observed difference in muscle activation.

The one finding that was consistent across all three subjects was the difference in electromyographic activity that was obtained in the two test positions. There is certainly strong evidence that the supine position is capable of producing greater amounts of background EMG than the sitting position. Initially this was considered desirable because, as noted previously, higher amounts of background EMG have been correlated with higher VEMP amplitude. Clinically, one would want amplitude to be as high as possible to facilitate identification, especially since merely judging the response present or absent is sometimes the desired objective of VEMP testing. However, after examining the relationships obtained in the subjects of this study, it is not so clear that background EMG had a lot of influence on VEMP amplitude for these three subjects.

Future studies of VEMPs could concentrate on describing 500 Hz tone burst-evoked VEMPs more thoroughly, perhaps expanding the experiment to include an examination of response threshold. It would also be valuable to discover, if possible,

why click stimuli had such a poor rate of success at evoking VEMPs. This experiment demonstrated high variability in several aspects of the VEMP, which was attributed in large part to the small sample size. Future studies would be advised to have a larger *n* and discover whether variability reduces or increases as a result.

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