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OCULAR VESTIBULAR EVOKED MYOGENIC POTENTIALS (OVEMP) USING AIR CONDUCTED SOUND: EFFECT OF BODY POSITION ON THRESHOLD

by

Andrea Rae O'Neil

A Capstone Project
submitted in partial fulfillment of the
requirements for the degree of:

Doctor of Audiology

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Program in Audiology and Communication Sciences

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Approved by:
Belinda Sinks, Au.D., Capstone Project Advisor
Maureen Valente, Ph.D., Second Reader

Abstract: The primary objective of this research study is to determine if various body positions for ocular vestibular evoked myogenic potential (oVEMP) testing demonstrate differentiation of the saccule and utricle through threshold responses.

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ABBREVIATIONS

AEP	Auditory Evoked Response
cVEMP	Cervical Vestibular Evoked Myogenic Potential
dB	Decibel
EMG	Electromyographic
GEEs	Generalized Estimating Equations
Hz	Hertz
ms	Milliseconds
nHL	Normative Hearing Level
NR	No Response
oVEMP	Ocular Vestibular Evoked Myogenic Potential
SCM	Sternocleidomastoid
SPL	Sound Pressure Level
VEMP	Vestibular Evoked Myogenic Potential

INTRODUCTION

Diagnostic testing of the vestibular system is an essential component of treating patients with balance dysfunction. Until recently, testing methods primarily evaluated the integrity of the horizontal semicircular canal, which is only a portion of the vestibular system. Recent advances in technology have afforded clinicians the ability to assess otolith function through Vestibular Evoked Myogenic Potential testing. This newly developed procedure augments the management of dizzy patients by increasing specificity when investigating the site of lesion.

Vestibular Evoked Myogenic Potential (VEMP) is a short latency muscle potential that is created when the vestibular system is presented with loud sound. Evoked by acoustic, bone or galvanic stimulation, the VEMP is a biphasic potential that represents the response of the otolith organs to loud stimulation. The myogenic potential may be recorded from various locations. The primary recording site that is used clinically is the sternocleidomastoid (SCM) along the cervical spine. Despite its benefits, the procedure still has limitations in regards to eliciting a VEMP response from the SCM of patients with poor muscle tone, poor range of motion in the neck and the pediatric and geriatric populations. VEMP testing from inferior extraocular muscles of the eye is of recent research interest. This new variation of the VEMP procedure may supplement conventional testing in difficult-to-test populations or possibly may be able to evaluate previously inaccessible information about the vestibular system. However, to develop a new clinical test of the vestibular system, one must analyze previous research to fully understand the system.

Historical Research

The vestibular system's response to sound has not always been clearly understood. It was first suspected to be sensitive to sound in the early twentieth century. Pietro Tullio (1929)

hypothesized that loud sounds generate vestibular symptoms in patients. His postulation was further developed by Georg von Békésy (1935), who hypothesized that high intensity sounds greater than 125 dB SPL would affect the vestibular system, which was confirmed by vestibular responses in his subjects. Eventually, the occurrence of vestibular symptoms induced by loud stimuli became known as the "Tullio Phenomenon." Technological advances in electropotential recordings and inquiries about the Tullio Phenomenon supported initial physiologic studies in animals and humans evolving into VEMP testing (as cited in Hall, 2007).

The human inner ear contains the end organ for hearing (cochlea) and the end organs for balance (the semicircular canals and the otolith organs (saccule and utricle)). This separation of function has not always existed. Lower species of vertebrates such as fish and rays utilize the otolith organs, specifically the saccule, as a duel receptor for both balance and hearing (Lowenstein & Roberts, 1951). As animals evolved, the cochlea was developed in humans to process sound (Popper, Platt, & Saidel, 1982). Nevertheless, some of the saccule's ability for auditory reception has been preserved in a variety of mammals such as the guinea pig, squirrel monkey and cat (Cazals, Aran, Erre, Guilhaume, & Aurosseau, 1983; McCue & Guinan, 1994; McCue & Guinan, 1995; Young, Fernández, & Goldberg, 1977) .

Animal studies allowed researchers to record electropotentials from sites that were not feasible in humans. Direct recordings of neurologic potentials in humans were not possible due to the surgical techniques necessary to access the vestibular branches of the vestibulocochlear cranial nerve. Consequently, the muscular response to the sound-activated vestibule was analyzed to determine if the response was cochlear or vestibular in origin.

Early human studies utilized the inion as a prime recording site for potentials. Electroencephalographic electrodes recorded cervical myogenic activity in response to a click

stimulus both monaurally and binaurally. The response was initially hypothesized to be cortical in nature (Geisler, Frishkopf, & Rosenblith, 1958), but Bickford and colleagues determined that the inion potential was vestibular in origin rather than auditory (1964). The potentials were myogenic because changes in muscle tension eliminated the response when no muscle flexion was exerted. The response was maintained when muscle tension was produced (Bickford, Jacobson, & Cody, 1964).

Further attempts were made to record the response from both normal subjects as well as those with auditory and/or vestibular abnormalities. When testing subjects with both unilateral and bilateral auditory deafness but intact bilateral horizontal semicircular canal function verified by caloric testing, the myogenic responses were sustained. Similarly, a subject with unilateral deafness and loss of unilateral vestibular function showed no myogenic response on the impaired side while the same subject's normal auditory and vestibular functioning contralateral side produced myogenic responses when stimulated (Bickford et al., 1964).

Although research examining the vestibular system's response to sound had occurred since the early twentieth century, the theories were not applied to clinical research until 1992 when Colebatch and Halmagyi studied electromyographic (EMG) activity in the sternocleidomastoid muscle before and after unilateral vestibular nerve deafferentation.

Using auditory evoked response (AEP) equipment with an acoustic click stimulus, Colebatch and Halmagyi recorded a positive response at approximately 13 milliseconds (ms) (p13) and a negative response at approximately 23 ms (n23) in a subject with Meniere's disease when the subject contracted the sternocleidomastoid muscle. Following the nerve section, EMG activity was obliterated on the side ipsilateral to the deafferentation but was preserved on the contralateral side. Colebatch and Halmagyi hypothesized that the p13n23 response was

vestibular in nature and was a feasible tool to augment a clinician's understanding of the vestibular system (Colebatch & Halmagyi, 1992; Colebatch, Halmagyi, & Skuse, 1994).

Cervical Vestibular Evoked Myogenic Potentials

Colebatch and colleagues' inquiries lead to Cervical Vestibular Evoked Myogenic Potentials (cVEMP), which are used clinically. The cVEMP tracing consists of a positive peak at approximately 13 ms and a negative peak at approximately 23 ms (Fig. 1) and represents the saccule's response to sound when using an air-conducted stimulus (Colebatch et al., 1994; Murofushi & Curthoys, 1997; Todd, Cody, & Banks, 2000; Welgampola & Colebatch, 2001). To elicit the air-conducted cVEMP response, the stimulus must be a brief click or a low frequency (e.g. 500 Hz) tone burst. The 500 Hz toneburst has been shown to best stimulate the saccule (Colebatch et al., 1994; Rauch, Zhou, Kujawa, Guinan, & Herrmann, 2004; Todd et al., 2000; Welgampola & Colebatch, 2001). Both otolith organs (i.e. the saccule and the utricle) are activated when stimulated via bone conduction (Brantberg Tribukait, & Fransson, 2003). Based on robustness of amplitude and SCM activity, cVEMP testing is most successful when the patient lies supine with head elevated and turned away from the stimulated ear (Isaacson, Murphy, & Cohen, 2006).

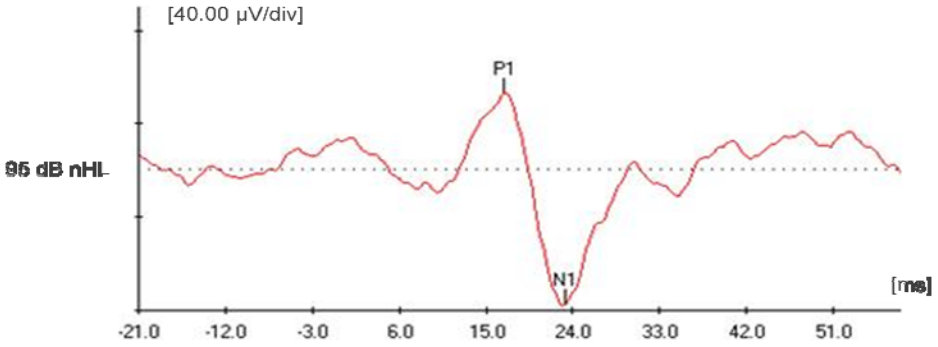

Figure 1. *Normal cVEMP response elicited with a 500 Hz tone burst via air conduction, showing p1 and n1 peaks with their latencies.*

Air-conducted cVEMPs are more clinically used due to their specificity of evoking a saccular response than bone conduction or galvanic stimulation. Therefore, all further cVEMP information will be referencing an air-conduction stimulus. The stimulus is presented at a loud intensity (e.g. 95 dB nHL) to ascertain the integrity of the saccule and its corresponding neurophysiologic mechanisms. Once function of the system is confirmed, intensity is then decreased to search for a cVEMP threshold, which represents the softest intensity level a cVEMP tracing is present and repeatable. Cervical VEMP responses for both integrity and threshold inquiries are recorded from an inhibitory response on a tonic SCM on the side ipsilateral to stimulation (Colebatch & Rothwell, 2004; Hall, 2007). Figure 2 demonstrates the electrode montage for cVEMP testing with the left sternocleidomastoid muscle flexed for data collection. Amplitude of the response represents the gain of the positive and negative cVEMP peaks. Amplitude values of the cVEMP directly relate to tonicity of the muscle and the intensity of the stimulus (Colebatch et al., 1994). Normative threshold values are dependent upon clinic norms.

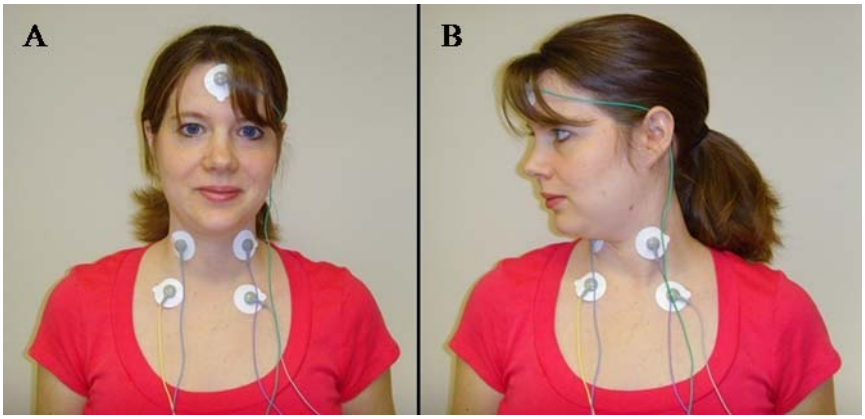

Figure 2. *A. Electrode montage for cVEMP testing.*
B. Left sternocleidomastoid muscle flexed.

When interpreting results, amplitude, latency and threshold may then be analyzed for interaural differences within the patient or compared with clinic norms. The utilization of

cVEMP testing has been clinically applied to determine otolith function. Furthermore, cVEMP testing aids in differential diagnosis of multiple vestibular pathologies: acute vestibular neuritis (Brantberg et al., 2003), Ménière disease (Welgampola & Colebatch, 2005; Young, Wu, & Wu, 2002), vestibular schwannoma (Murofushi, Matsuzaki, & Mizuno, 1998), multiple sclerosis (Shimizu, Murofushi, Sakurai, & Halmagi, 2000) and superior canal dehiscence (Brantberg and Verrecchia, 2009; Colebatch et al., 1998; Watson, Halmagyi, & Colebatch, 2000; Welgampola & Colebatch, 2005).

Anatomy and Neural Pathways

The aforementioned p13n23 cVEMP waveform is a myogenic potential arising from the vestibulocollic reflex of the vestibulospinal tract, which is used to maintain head and neck stability. The cVEMP is in response to sound and originates from the vestibular system, most likely the saccule (Colebatch et al., 1994; Todd et al., 2000). A later response, n34p44, is independent of the vestibular system and most likely arises from the cochlea (Colebatch et al., 1994).

A comprehensive understanding of the cVEMP origin and neuronal pathways of the response is necessary to implement the test clinically. Figure 3 illustrates the cVEMP pathway, as it is known to date. The cVEMP arises from the otolith organs, which has been shown by preserved cVEMP findings in subjects with non-functioning cochleae and/or abnormal semicircular canals (Sheykholeslami & Kaga, 2002).

Once the saccule has been activated by sound, neural firing occurs through the afferent system along the vestibulocochlear cranial nerve. The nerve has two branches that receive sensory input from the organs of the inner ear labyrinthine: auditory and vestibular. The vestibular portion further bifurcates into superior and inferior sections. The saccule is innervated

by both the superior and inferior segments with the superior receiving activity from the anterior portion of the saccular maculae and the inferior receiving activity from the posterior maculae, though the inferior portion is mainly responsible for cVEMP responses. The vestibulocochlear nerve is comprised of myelinated, bipolar neurons with somas housed within the internal auditory meatus of the petrous portion of the temporal bone. The hair cells of the saccule synapse primarily on the inferior portion of the vestibulocochlear nerve, which acts as the first order neuron (Hall, 2007; Haque & Dickman, 2008).

Four vestibular nuclei lie within the medulla and pons junction of the brainstem: lateral, medial, superior and inferior. The inferior vestibular nerves originating within the saccule travel mostly to the inferior vestibular nuclei then descends via the medial and lateral vestibulospinal tracts (Haque & Dickman, 2008). However, findings have been inconsistent in attributing more responsibility to the medial tract than the lateral (Colebatch et al., 1994; Hall, 2007; Kushiro, 1999; Todd et al., 2000; Zhou & Cox, 2004).

The descending fibers connect to the motor nuclei of the accessory nerve, which is responsible for the sternocleidomastoid muscle of the neck. Hall explains that "from the motor nucleus of cranial nerve XI [accessory], nerve fibers take a rather indirect route from the medulla, through a cranial opening (jugular foramen) and then to neck muscles (SCM and trapezius muscles)" (2007, p. 605). The synapse at the level of the SCM muscle creates an inhibitory biphasic myogenic response when recorded from the SCM in a tonic state (Colebatch and Rothwell, 2004).

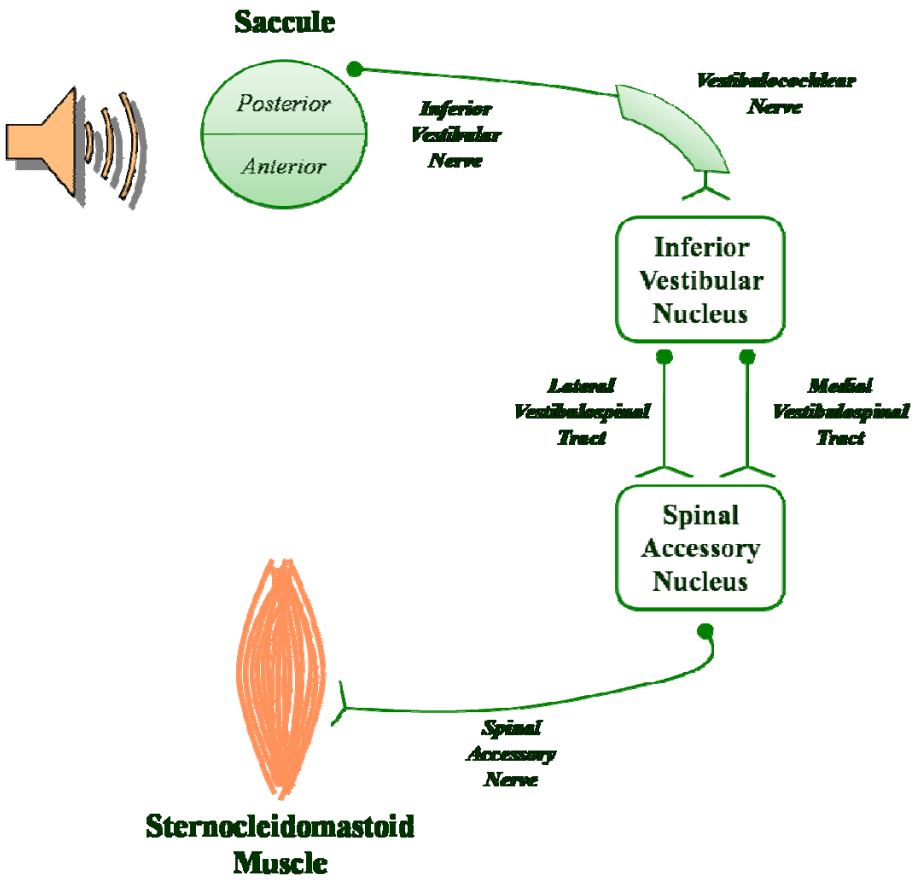

Figure 3. *Diagram of the cVEMP neural pathway evoked by an air-conducted stimulus.*

Ocular Vestibular Evoked Myogenic Potentials

The discovery of the cVEMP response and its neuronal pathway encouraged researchers to explore the procedure's stimulation and recording methods. Investigations by Todd and colleagues (2003) demonstrated a short latency vestibular evoked potential with a negative peak at 10 ms (n10) and a positive peak around 15 ms in response to a loud 500 Hz bone-conducted stimulus when recording from Cz and Fpz, which are the at the vertex and midline of the brow, respectively. Figure 4 is an example of an n10 response found in a normal subject. The thresholds of these responses were similar to the subjects' cVEMP thresholds, were present in subjects with and without hearing loss, were not present in subjects with hypoactive vestibular

systems and were present in subjects with hyperactive vestibular symptoms (Todd, Rosengren, & Colebatch, 2003).

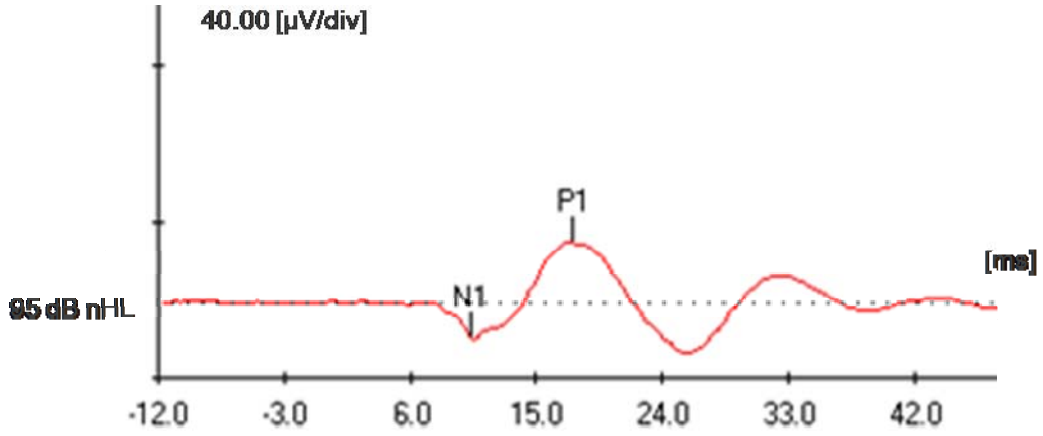

Figure 4. *Ocular VEMP response at 95 dB nHL with 500 Hz stimulus found for subject 22. Waveform was obtained while patient was sitting upright.*

These findings led to postulations that the response was vestibular, and possibly saccular, in nature. Rosengren and colleagues (2005) did not see the n10 component in normal patients when using a high frequency bone-conducted stimulus, which is consistent with previous findings that suggest that the otolith organs are most sensitive to low frequencies (Sheykholeslami, Kermany, & Kaga, 2001). Further research confirmed that the n10 component response was vestibular in origin and most likely originating from the otolith-ocular pathway (Chihara, Iwasaki, Ushio, & Murofushi, 2007; Govender, Rosengren, & Colebatch, 2009; Iwasaki, et al., 2008; Rosengren, Todd, & Colebatch, 2005; Todd, Rosengren, Aw, & Colebatch, 2007; Wang, Jaw, & Young, 2009).

With its origins in the otolith organs, n10 responses are best recorded from extraocular muscles slightly below the eye contralateral to stimulation (Rosengren et al., 2005). The potential is not in response to eye movement but instead is myogenic in nature and arises from the

vestibulo-ocular reflex (Chihara et al., 2009; Rosengren et al., 2005; Todd et al., 2007; Welgampola, Migliaccio, Myrie, Minor, & Carey, 2009). The n10 component potential travels through the vestibular pathway and is recorded from the contralateral inferior oblique muscle when in a flexed state (Rosengren et al., 2005) though others hypothesize that the inferior rectus may also contribute to the response (Welgampola et al., 2009). Todd et al. (2007) infer from previous cVEMP research (Colebatch & Rothwell, 2004) that the n10 response at the level of the extraocular muscles is excitatory because of its initial negative peak response.

The inferior extraocular muscles are best activated when eyes are in superomedial gaze (Chihara et al., 2007; Govender et al., 2009; Rosengren et al., 2005; Wang et al., 2009; Welgampola et al., 2009). Rosengren et al. suggest that the recording of extraocular potentials could "extend the range of central and peripheral vestibular and ocular pathways that can be assessed electrophysiologically" (2005, p. 1947). The method of recording n10 VEMP information from an extraocular position was thus named Ocular Vestibular Myogenic Evoked Potential (oVEMP).

From analyzing the aforementioned research, Rosengren, Welgampola, & Colebatch (2010) posits the neuronal pathway for oVEMP via the vestibulo-ocular reflex: activation of the vestibular nerve and vestibular nuclear complex traveling up the medial longitudinal fasciculus where at some point it decussates ending at the oculomotor nuclei, ocular nerves and the extraocular muscles.

As the oVEMP pathway is being confirmed, researchers are simultaneously studying oVEMP findings. Various stimulation methods elicit the oVEMP response: air conduction, bone conduction, forehead tap and galvanic stimulation, though air and bone conduction stimulation are the most studied. When using an air-conducted stimulus, a 500 Hz tone burst is more

effective in producing optimal results than when using a click stimulus (Chihara et al., 2007). Air and bone conduction oVEMP responses are shown to have similar tuning frequencies (i.e. 500 Hz tone burst) as cVEMP responses (Park, Lee, Shin, Lee, & Park, 2010; Rosengren et al., 2005; Todd et al., 2003; Todd et al., 2007). Compared to the cVEMP, though, Park et al. (2010) argue that the cVEMP is a more reliable and robust measure than oVEMP testing. Air conduction oVEMPs can be obtained through a monaural or binaural stimulus presentation with similar results (Wang et al., 2009). Normal oVEMP thresholds are approximately 80 to 90 dB nHL when using a 500 Hz air-conducted stimulus and when obtained in a sitting position (Park et al., 2010; Wang et al., 2009).

While stimulus parameters and subsequent threshold normative values have been obtained for oVEMP testing, the effects of body position are still poorly understood. Govender et al. (2009) explored the effects of body position, head rotation and vision on the oVEMP response. These investigators did not find significant results with changes in head rotation or vision. However, they did discover that body position with the trunk at a 30º angle affects oVEMP amplitude, which is in contrast to the typical sitting position during oVEMPs in previous studies. After a review of the literature, it is evident that further understanding of the oVEMP is warranted.

The current study investigated oVEMP positioning techniques to enhance future oVEMP procedures. The tested hypothesis states that by manipulating body position, a differentiation of the saccule from the utricle during oVEMP testing may be obtained. Because of the anatomical orthogonal orientation of the otolith maculae, differential gravity-specific resting potentials should arise during specific body positioning as a result of the gravitational forces on the saccular versus utricular otoconial membranes.

METHODS

Subjects

Ocular VEMPs were performed on healthy adult volunteers from the Washington University and St. Louis communities. This study was approved by the Human Research Protection Office at Washington University School of Medicine. The subjects participating in this study gave written informed consent.

Thirty ears (27 female and 3 male; 20 – 53 years; mean age 27.7 ± 7.5 years) were evaluated with oVEMP testing while situated in four positions to gather threshold information. Participants completed the patient questionnaire from Washington University School of Medicine Department of Otolaryngology-Head and Neck Surgery Dizziness and Balance Center to confirm no prior history of vestibular dysfunction or chronic conductive hearing loss. The questionnaire is listed in Appendix A. Testing occurred in one session lasting approximately ninety minutes. Throughout testing, participants were allowed rest periods to reduce fatigue and boredom.

Preparation

Otoscopy was performed bilaterally to confirm no occlusion in the external auditory canal. Facial skin was cleaned prior to surface electrode placement. A clean gauze cloth was used under the eyes and on the cheeks. A gauze cloth with NuPrep skin abrasive was rubbed on the forehead to obtain acceptable electrode impedances. Impedances were maintained below 5 kΩ. Figure 5 depicts the oVEMP montage: the ground electrode was place on the high forehead (Fz), active electrodes were placed approximately 1 centimeter inferior to the lower eyelids and reference electrodes were placed immediately inferior to the active electrodes.

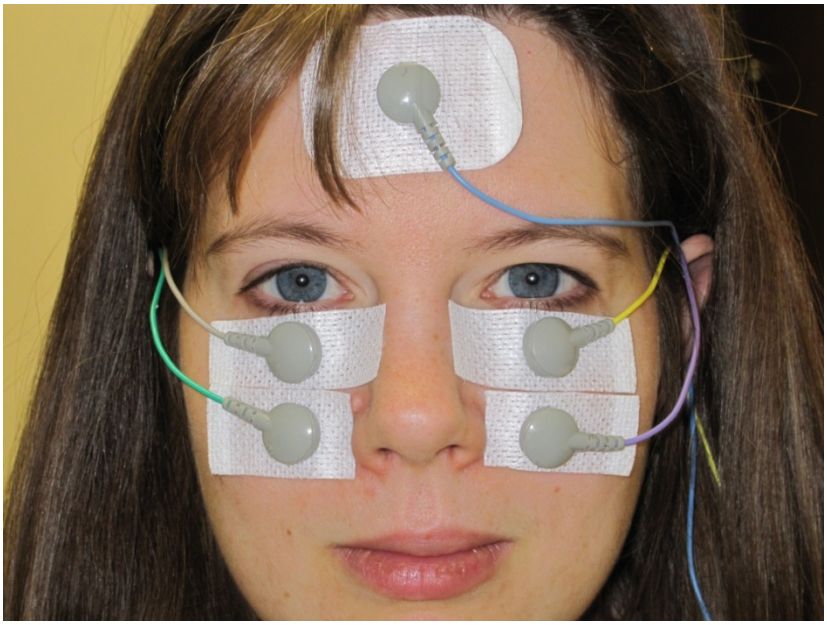

Figure 5. *Photograph of oVEMP montage.*

Stimulus and Recording Parameters

A Natus Bio-Logic Navigator Pro auditory evoked potential unit was used to obtain and average oVEMP activity. The stimulus and collection parameters described by Wang et al. (2009) were simulated for this study and are summarized in Table 1. For parameter measures that were not addressed in Wang et al. (2009), the authors used cVEMP parameters from the Washington University Dizziness and Balance Center. A 500 Hz tone burst was presented via Bio-logic standard foam insert earphones. The stimulus was presented with rarefaction polarity, Blackman ramping (two cycles plateau and one cycle rise and fall times) and a stimulation rate of 5 Hz. One-hundred sweeps of electromyogenic (EMG) activity were recorded on the side contralateral to acoustic stimulation. The activity was collected with a -10.5 ms pre/post stimulus time, was amplified (at a gain of 5,000) and was filtered (1-1000 Hz). An artifact rejection system was used.

Parameters	Selection
Stimulus	
▪ **Transducer**	Insert earphones with 0.8 ms delay
▪ **Type**	500 Hz tone burst
▪ **Ramping**	Blackman
o **Duration**	2 cycles plateau; 1 cycle rise/fall
▪ **Intensity**	70 – 95 dB nHL
▪ **Polarity**	Rarefaction
▪ **Rate**	5 Hz
Acquisition	
▪ **Analysis time**	
o **Epoch time**	106.6 ms
o **Pre/post stimulus**	- 10.5 ms
▪ **Blocking**	2.9 ms
▪ **Electrode type**	Surface (Ag/AgCl)
▪ **Electrode location**	
o **Noninverting**	1-3 cm under eye on inferior oblique
o **Inverting**	Directly under noninverting electrode on cheek
o **Ground**	High forehead
▪ **Filter settings**	1 – 1,000 Hz
▪ **Notch**	None
▪ **Amplification**	5,000
▪ **Sweeps**	100

Table 1. *Ocular VEMP parameters adapted from Wang et al. (2009) and Washington University Dizziness and Balance Center cVEMP parameters.*

Positioning

Ocular VEMP testing was performed separately in the right and left ear while the subject remained in four different positions. The patient's head was positioned so that the vestibular system was at 30º angle in order to isolate the saccule. Figure 6 demonstrates that in position A, the subject sat upright with head level. In position B, the subject laid supine with chin tilted 30º toward the chest. In position C, the subject laid on the right side with chin tilted 30º toward the chest. In position D, the subject laid on the left side with chin tilted 30º toward chest. The order of body positions and the order of ears tested were randomized to control for fatigue.

While in these four positions, oVEMP testing was recorded bilaterally with the 500 Hz tone burst stimulus being presented monaurally as the subject contracted the inferior oblique muscle by elevating the eye 20º. For optimal muscle tension during elevation, the subject was instructed to maintain gaze fixation on targets that were premeasured to control for angle of eye gaze (e.g. a video-oculography lightbar with the light prepositioned at 20º vertical elevation for position A and premeasured markers on the walls and ceiling while the medical table was fully raised 31 inches for positions B, C and D). The gaze fixation targets preserve an eye elevation angle of 20º.

Figure 6. *Ocular VEMP positions. A: Sitting upright position with chin level and eyes elevated 20º to target on lightbar. B: Lying supine with chin tilted down and eyes elevated 20º to target on ceiling. C: Lying on right side with chin tilted down and eyes elevated 20º to target on wall. D: Lying on left side with chin tilted down and eyes elevated 20º to target on wall.*

Procedure

For each subject, the sequence of positions A, B, C and D was randomized to control for fatigue. Before testing, the participant was instructed to look at a target with head in the intended position during the stimulus, which should be loud but not uncomfortable. Figure 7 depicts the threshold search for a normal subject sitting upright using a 500 Hz tone burst stimulus. Two waveform responses were obtained sequentially and the subject was allowed to rest in between each pair of oVEMP trials. The stimulus was presented at 95 dB nHL for all participants and was replicated to confirm both present and absent responses. If a response was present, the intensity was decreased in 5 dB nHL increments until the oVEMP threshold was found. The threshold and the intensity level below threshold were replicated to guarantee an accurate threshold recording. This process of finding thresholds was performed in both ears during all four positions.

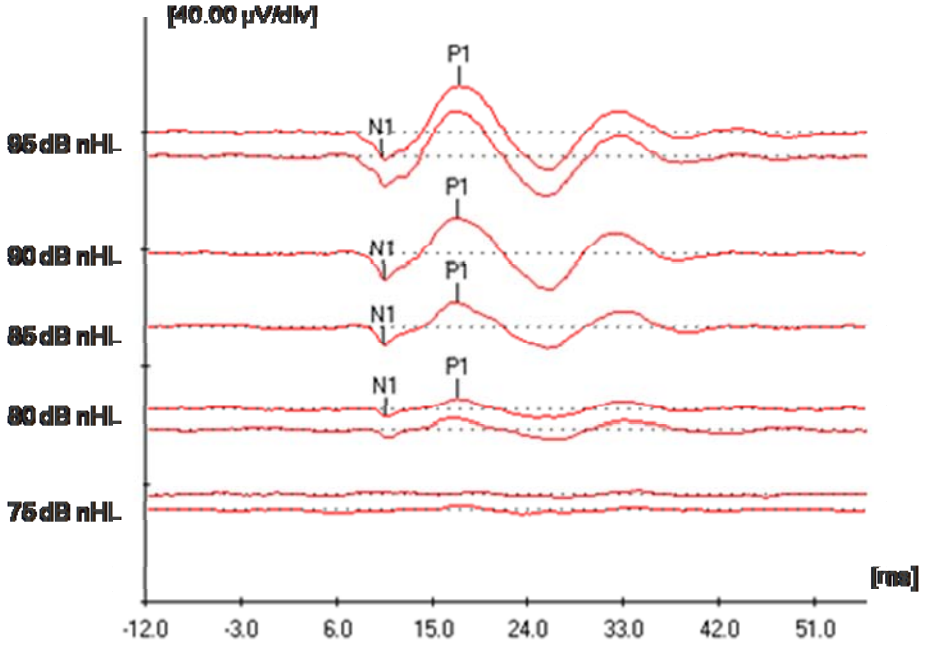

***Figure 7**. Threshold search for oVEMP testing with subject sitting upright. Response was replicated at 95 dB nHL, at the threshold of 80 dB nHL and at the first non-threshold response at 75 dB nHL.*

RESULTS

Each of the 30 observations contributed data at each of the four positions used for testing: sitting upright, lying supine, lying on the right side and lying on the left side. Appendix B shows threshold responses for each individual, which ranged from 75 dB nHL to 95 dB nHL with some subjects having no response for certain positions. Table 2 demonstrates average threshold responses that were calculated for mean with standard deviation, median and mode for each position; however, observations that did not yield an oVEMP response were excluded from average data.

Threshold Data				
Values in dB nHL	Sitting Upright	Lying Supine	Lying on Right	Lying on Left
Mean	85 ± 4	86 ± 5	86 ± 5	85 ± 4
Median	85	85	85	85
Mode	85	85	85	85

Table 2. *Data for threshold values. Observations that did not yield an oVEMP response were not included in this calculation.*

Figure 8 illustrates the percentage of present oVEMP responses per position regardless of threshold values for present responses. The lying supine and sitting upright positions elicited the most oVEMP responses in participants with present responses in over ninety percent of the participants. Ocular VEMP responses were present in approximately eighty-six percent of the observations where the subject laid on the right or left side. Although the lying supine position elicited the most present oVEMP responses, it did not produce the greatest amount of *best* threshold responses compared to sitting upright. This trend is further explained in Table 6.

Figure 8. *Percentage of present oVEMP responses in each position from 30 observations.*

Generalized Estimating Equations (GEEs) were utilized to account for the correlation of multiple measurements within each observation across positions. Table 3 shows that an analysis of the ordinal scaled variable (i.e. threshold value in dB nHL) was modeled with a multinominal probability distribution and cumulative logit link function to allow for GEE statistical analysis. This was to maintain ordering for the threshold responses since No Response findings did not have a numerical value.

Category	**Threshold Value (*dB nHL*)**
0	75
1	80
2	85
3	90
4	95
5	No Response

Table 3. *Threshold responses were assigned a category to maintain ordinal value since No Response findings did not have an inherent value. This category assignment was used for multinominal probability distribution.*

Analysis of binary variables was modeled with binomial probability distributions and logit link functions. Statistical contrasts within the GEE model were used to compare each position to each of the other positions. Table 4 is an example of a cross tabulation of participants' thresholds when sitting upright compared with when lying supine. Data entries indicate the number of participants whose thresholds increased, decreased or remained the same from the sitting upright position to the lying supine position. Similar cross tabulations were constructed to compare threshold changes between each position and are shown in Appendix C (i.e. sitting upright vs. lying supine, sitting upright vs. lying on the right side, sitting upright vs. lying on the left side, lying supine vs. lying on the right side, lying supine vs. lying on the left side and lying on the right side vs. lying on the left side).

To describe the cross tabulation table, three cells are highlighted. The cell highlighted purple indicates that for four participants, their thresholds when sitting upright were 80 dB nHL and increased to 85 dB nHL when lying supine. The cell highlighted pink represents nine subjects whose thresholds remained at 85 dB nHL in both the sitting upright and lying supine positions. The blue cell indicates one participant's threshold decreased from 90 dB nHL to 85 dB nHL when in the sitting upright and lying supine positions, respectively.

		Sitting upright (*dB nHL*)					
		75	80	85	90	95	NR
Lying supine (*dB nHL*)	75	0	1	0	0	0	0
	80	0	4	1	1	0	0
	85	0	4	9	1	0	0
	90	0	0	1	2	1	0
	95	0	0	2	1	0	1
	NR	0	0	0	0	0	1

Table 4. *Cross tabulation of thresholds across positions. NR = No Response. Number of participants whose thresholds increased (purple), remained the same (pink) or decreased (blue) when changing from the upright position to lying supine regardless of sequence.*

The GEE analysis revealed no statistical significance when comparing thresholds across all four positions (p = 0.33). Table 5 shows that when evaluating individual comparisons of thresholds between each position, only trends were seen.

Positions Compared			p-values
Upright	vs.	Supine	0.42
Upright	vs.	Right Side	0.08
Upright	vs.	Left Side	0.17
Supine	vs.	Right Side	0.21
Supine	vs.	Left Side	0.29
Right Side	vs.	Left Side	0.69

Table 5. *Individual GEE comparisons between each position's thresholds for the 30 observations.*

Table 6 illustrates further investigations comparing each of the four positions when they produced the *best* and the *worst* thresholds for an observation. To categorize a position as *best* or *worst* for each observation, each position received a score of 0 or 1 if a position did not elicit the lowest threshold for this observation or if a position did elicit the lowest threshold for this observation, respectively. No response (NR) was scored with an artificial ceiling value of 100 dB nHL. If ties across positions were present, each tying position received the same score.

For example, if position A elicited a threshold of 75 dB nHL and the remaining positions elicited a threshold of 95 dB nHL, position A would be classified with a 1 for the *best* comparison and the remaining positions would be scored as 0 for the *best* comparison. Conversely, position A would be scored with a 0 and the remaining positions would be scored as a 1 for the *worst* comparison. Due to many positions eliciting the same thresholds across all four positions for a given observation, comparisons were made without these uninformative observations and categorized into both *best* and *worst* conditions. All data were analyzed for trends.

Outcome	Value	Position				p-values
		Sitting Upright	Lying Supine	Lying on Right Side	Lying on Left Side	
Position elicits the best/worst threshold (yes/no), proportion of observations	*Best*	22 (73%)	17 (57%)	16 (53%)	17 (56%)	0.29* U vs. S, p=0.13 U vs. R, p=0.11 U vs. L, p=0.20 S vs. R, p=0.81 S vs. L, p=1.00 R vs. L, p=0.74
	Best, after dropping uninformative (n=23) §	15 (65%)	10 (43%)	9 (39%)	10 (43%)	N/A
	Worst	13 (43%)	13 (43%)	19 (63%)	16 (53%)	0.30* U vs. S, p=1.0 U vs. R, p=0.08 U vs. L, p=0.41 S vs. R, p=0.11 S vs. L, p=0.41 R vs. L, p=0.44
	Worst, after dropping uninformative (n-23) §	6 (26%)	6 (26%)	12 (52%)	9 (39%)	N/A

Table 6. *Comparison when each position elicits the best/worst threshold. U = sitting upright, S = lying supine, R = lying on right side and L = lying on left side. * P-value by GEE with multinomial distribution where thresholds were converted to a 0-5 scale listed in Table 3. To categorize as "best" and "worst," each observation is given a score of 0 or 1 depending on if the position gives the best or worst threshold for that observation. § Indicates "uninformative" observations, which are defined as observations where all four positions achieved the same threshold.*

Some subjects contributed data for more than one side. Due to sample size limitations, the additional within-subject correlation of data from the same patient could not be included in the model. Individual randomizations were obtained for each participant's sequence of positions.

Randomizations produced fifteen different sequences; therefore, some sequences had only one to two observations. A "sequence effect" could not be assessed because of limited sample size.

Each of the four positions' threshold values were compared for fatigue based on their sequence within the test battery. Comparisons of threshold values were made for observations where that particular position was the last tested position versus the threshold value for the observations where that position was not the last tested position. For example, sitting upright was the last of the four positions tested in five of thirty observations; therefore, sitting upright was not the last position tested for twenty-five observations. A Wilcoxon's 2-sample test showed no statistically significant differences in the threshold achieved when a given position was the final test performed compared to when a given position was not the final test performed. This analysis showed no statistical differences in thresholds for all positions indicating no observable patient fatigue related to the order a given position fell within the test battery.

DISCUSSION

The hypothesis of this pilot investigation was to determine if a differentiation of the saccule from the utricle could be obtained by manipulating body position during oVEMP testing and to determine if changes in oVEMP threshold were present when body position was a variable. Although the current study could not delineate the organ that contributes to the oVEMP response and its pathway, findings did indicate trends in the data. The mean oVEMP thresholds of the participants within this study (85 ± 4 dB nHL) fell within the normal threshold range (80 – 90 dB nHL) of previous studies (Park et al., 2010; Wang et al., 2009), which indicates that the selected participants' results were consistent with findings of previous studies. Furthermore, 85 dB nHL was commonly observed throughout all positions in mean, median and mode values, when examining threshold data for observations that produced waveform responses. Therefore,

the thresholds obtained in this study do not only fall within the previously suggested range of normal for oVEMPs, but the findings affirm the aforementioned normal threshold range.

Although no statistical significance was found, trends were seen in the data. The GEE analysis resulted in trends indicating that having participants sit upright during oVEMP testing is optimum for achieving the best threshold possible. When evaluating which position elicited a participant's best threshold, sitting upright was the best position for 73% of the observations. This is compared to lying supine, lying on the right side and lying on the left side, which all elicited the best threshold response for approximately 50% of the observations. Sitting upright maintained 65% of the best threshold responses even when uninformative observations (i.e. observations in which the same threshold was obtained for each position) were discarded. This is in contrast to the suggested supine position for cVEMPs (Isaacson et al., 2006) and the suggested supine position for oVEMPs (Govender et al., 2009). However, the trend found in this study may support the idea that the sitting upright position may best differentiate the otolith organs and that the sitting upright position should be recommended for future oVEMP testing.

This study experienced limitations with sample size. Although thirty ears were evaluated, little variability was seen in the obtained thresholds. This could be due to the already small threshold range of normal subjects or due to the inherently small changes that the effect of positional change has on threshold responses.

Ocular VEMP parameters for the current study were adapted from Wang et al., (2009). Since the implementation of the present study's oVEMP data collection, recent publications (Rosengren et al., 2010) suggest using larger amplification during the acquisition of the response given that the oVEMP waveform is considerably smaller than the cVEMP response. Future studies should utilize this suggestion for better visualization of the waveform.

CONCLUSION

The findings in this study suggest that normal oVEMP thresholds range from 80 to 90 dB nHL. This study further supports continued research of oVEMP testing while subjects are in a sitting upright position. Although the current study found only trends supporting testing in this position, additional investigation of positional testing may be warranted to determine if position during oVEMP testing differentiates the otolith organs. By studying specific populations (e.g. subjects with a deafferented inferior vestibular nerve), future research may be able to better understand the oVEMP neuronal pathway and its originating organ(s) when evoked by an air-conducted stimulus. Furthermore, future research should assess test-retest reliability of an air-conducted oVEMP response and should determine significant changes within oVEMP threshold values. Such standardization of equipment parameters, testing protocols and clinical uses is crucial for oVEMP testing to be fully implemented into a clinical setting.

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Appendix A

Washington University School of Medicine
Department of Otolaryngology-Head and Neck Surgery
Dizziness and Balance Center

Patient Name:_____ D.O.B:___/___/___ Sex: M___F___ Date: ___/___/___

The following questions refer to your feeling of dizziness. Please answer them as "yes" or "no" and fill in all blanks.

Please describe in your own words, the sensation you feel without using the word "dizzy":
_____
_____
_____

I. Do you ever have any of the following sensations?

Yes	**Spinning in circles**	**No**
Yes	**Falling to one side**	**No**
Yes	**World spinning around you**	**No**

II. The following refer to a typical dizzy spells:

Yes	**Do your dizzy spells come in attacks?**	**No**
	How often? _____	
	How long is the attack?_____	
	Date of first spell?_____	
Yes	**Are you free from dizziness between attacks?**	**No**
Yes	**Does your hearing change with an attack?**	**No**
Yes	**Are you dizzy mainly when you sit or stand up quickly?**	**No**
Yes	**Are you dizzier in certain positions?**	**No**
	Which position? _____	
Yes	**Are you nauseated during an attack?**	**No**
Yes	**Are you dizzy even when lying down?**	**No**
Yes	**Have you had a recent cold or flu preceding recent dizzy spells?**	**No**
Yes	**Have you had fullness, pressure, or ringing in your ears?**	**No**
Yes	**Have you had pain or discharge in your ear of recent onset?**	**No**
Yes	**Have you had trouble walking in the dark?**	**No**
Yes	**Are you better if you sit or lie perfectly still?**	**No**
Yes	**Do loud sounds make you dizzy?**	**No**

III. The following refer to other sensations you may have:

Yes	**Do you black out or faint when dizzy?**	**No**
	Have you had:	
Yes	**Severe or recurrent headaches?**	**No**
Yes	**Light sensitivity with your headaches or dizziness?**	**No**
Yes	**Any double or blurry vision?**	**No**
Yes	**Numbness in your face or extremities?**	**No**
Yes	**Weakness or clumsiness in arms, legs?**	**No**

Yes	**Slurred or difficult speech?**	**No**
Yes	**Difficulty swallowing?**	**No**
Yes	**Tingling around your mouth?**	**No**
Yes	**Spots before your eyes?**	**No**
Yes	**Jerking of arms or legs?**	**No**
Yes	**Seizures?**	**No**
Yes	**Confusion or memory loss?**	**No**
Yes	**Recent head trauma? (If yes, please explain)**	**No**

_____

_____

_____

IV. <u>The following refer to your hearing. Indicate which side has been affected</u>:

Yes	**Difficulty hearing in one ear?**	**Left**	**Right**	**Both**	**No**
Yes	**Ringing in one ear?**	**Left**	**Right**	**Both**	**No**
Yes	**Fullness in one ear?**	**Left**	**Right**	**Both**	**No**
Yes	**Change in hearing when dizzy?**				**No**
	Have you had any of the following?				
Yes	**Pain in ears?**	**Left**	**Right**	**Both**	**No**
Yes	**Discharge from ears?**	**Left**	**Right**	**Both**	**No**
Yes	**Hearing change?**				**No**
Yes	**Better?**	**Left**	**Right**	**Both**	**No**
Yes	**Worse?**	**Left**	**Right**	**Both**	**No**
Yes	**Exposure to loud noises?**				**No**
Yes	**Previous ear infections?**				**No**
Yes	**Trauma to your ear(s)?**				**No**
Yes	**Previous ear surgery?**				**No**
	What? _____				**No**
Yes	**Family history of deafness?**				**No**

V. <u>The following refer to habits and lifestyle</u>:

Yes	**Is there added stress to your life recently?**	**No**
Yes	**Are you dizzy or unsteady constantly?**	**No**
	Is your dizziness related to:	
Yes	**Moments of stress?**	**No**
Yes	**Menstrual period?**	**No**
Yes	**Overwork or exertion?**	**No**
Yes	**Do you feel lightheaded or have a swimming sensation when you are dizzy?**	**No**
Yes	**Do you find yourself breathing faster or deeper when excited or dizzy?**	**No**
Yes	**Did you recently change eyeglasses?**	**No**
Yes	**Have you ever had weakness or faintness a few hours after eating?**	**No**
Yes	**Do you drink coffee? How much? _____**	**No**
Yes	**Do you drink tea? How much? _____**	**No**
Yes	**Do you drink soft drinks? How much? _____**	**No**
Yes	**Do you drink alcohol? How much? _____**	**No**
Yes	**Do you smoke? What?_____ How much? _____**	**No**

Past Medical History:

Please list your current medical problems and length of illness:

_____

_____

Please list all surgery performed and approximate dates:

_____

_____

Please list all allergies (including drugs) and reaction:

_____

_____

Please list all medicines you currently take (including pain medicine, non-prescription medicine, nerve pills, sleeping pills, or birth control pills).

_____

_____

Have you had any previous testing (hearing, x-rays, head scans, etc.)?

_____

_____

Family History:
Any family history of:

Yes	**Migraine?**	**No**
Yes	**High blood pressure?**	**No**
Yes	**Low blood pressure?**	**No**
Yes	**Diabetes?**	**No**
Yes	**Low blood sugar?**	**No**
Yes	**Thyroid disease?**	**No**
Yes	**Asthma?**	**No**

Please list any other diseases that run in your immediate family:

_____

System Review:
Check all applicable symptoms:

Constitutional:			
☐ **Recent weight change**	☐ **Fever**	☐ **Fatigue**	☐ **N/A**
Eyes:			
☐ **Loss of Vision**	☐ **Pain**	☐ **Discharge/Tearing**	☐ **N/A**
☐ **Left** ☐ **Right** ☐ **Both**	☐ **Left** ☐ **Right** ☐ **Both**	☐ **Left** ☐ **Right** ☐ **Both**	
Ear, Nose, Mouth, Throat:	☐ **Facial weakness**	☐ **Nasal obstruction**	☐ **Nasal discharge**
☐ **Itchy ears**	☐ **Sneezing**	☐ **"Stuffy" nose**	☐ **Snoring**
☐ **Nosebleed**	☐ **Growth in nose**	☐ **Nasal bleeding**	☐ **Drooling**
☐ **Loss of sense of smell**	☐ **Chewing difficulty**	☐ **Lump in neck**	☐ **Dental problems/ Poorly fitting dentures**
☐ **Mouth growth, ulcer**	☐ **Heartburn**	☐ **Sore throat**	

☐ Pain on swallowing ☐ Voice changes	☐ Breathing difficulty	☐ N/A	☐ Bleeding from throat
Cardiovascular: ☐ Chest pain ☐ Leg pain with rest	☐ Irregular Heart Beat ☐ N/A	☐ Swelling of legs	☐ Leg pain with walking
Respiratory: ☐ Wheezing ☐ Coughing up blood	☐ Cough ☐ N/A	☐ Shortness of breath	☐ Mucous
Gastrointestinal: ☐ Decrease in appetite ☐ Diarrhea/Constipation	☐ Nausea/Vomiting ☐ Indigestion	☐ Blood in stool ☐ Food intolerance	☐ Difficulty swallowing (food sticks) ☐ N/A
Musculoskeletal: ☐ Neck Pain	☐ Joint pain/Stiffness	☐ Arthritis Name Joint:	☐ N/A
Skin: ☐ Rash	☐ Jaundice	☐ Recent baldness	☐ N/A
Neurological: ☐ Headache ☐ Tremor	☐ Blackout ☐ N/A	☐ Seizures	☐ Paralysis
Psychiatric: ☐ Insomnia	☐ Depression	On Medication: ☐ Yes ☐ No	☐ N/A
Endocrine: ☐ Thyroid trouble ☐ N/A	☐ Heat or Cold Intolerance	☐ Excessive sweating	☐ Excessive thirst, hunger, urination
Genitourinary: ☐ Painful urination ☐ Difficulty passing urine	☐ Veneral disease ☐ Incontinence	☐ Blood in urine ☐ N/A	☐ Frequent urination at night
Hematologic/Lymphatic: ☐ Anemia	☐ Bleeding problems ☐ Easy bruising	☐ Blood disorder (eg. Sickle Cell)	☐ N/A

Do you have anything else to tell us about your particular problem that we have not asked you on this questionnaire?

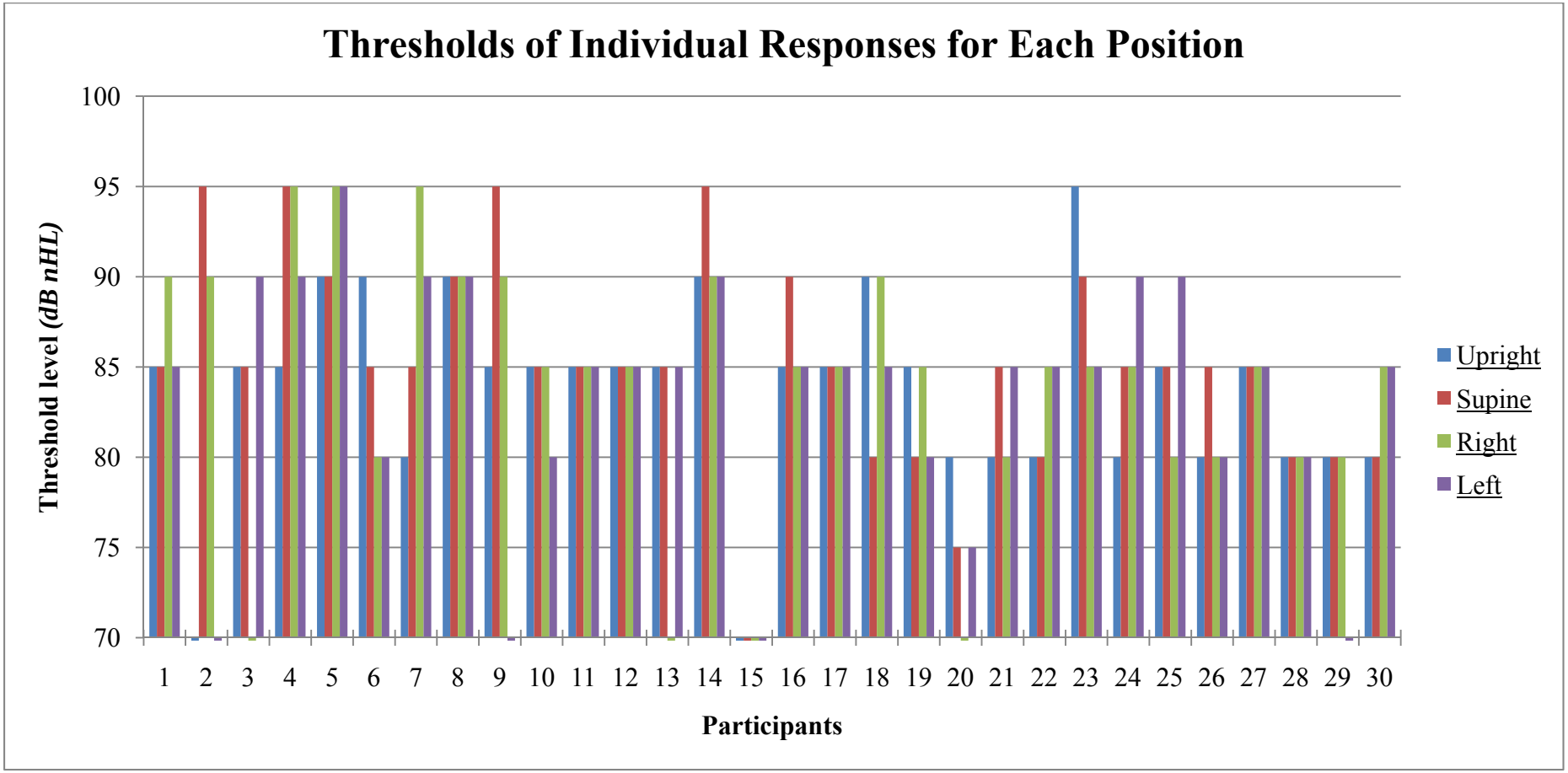
_____
_____
_____

Physician Review with Patient:

_____
_____
_____
_____
_____
_____

Physician Signature **Date**

Appendix B



Individual threshold levels obtained in each of four positions (i.e. sitting upright, lying supine, lying on the right side and lying on the left side) for all thirty participants. Observations with no threshold bar represent no oVEMP response with a 95 dB nHL stimulus.

Appendix C – *Cross tabulations of thresholds across positions.*

		Sitting upright (*dB nHL*)					
		75	80	85	90	95	NR
Lying on right side (*dB nHL*)	75	0	0	0	0	0	0
	80	0	4	1	1	0	0
	85	0	3	7	0	1	0
	90	0	0	2	3	0	1
	95	0	1	1	1	0	0
	NR	0	1	2	0	0	1
Lying on left side (*dB nHL*)	75	0	1	0	0	0	0
	80	0	2	2	1	0	0
	85	0	3	7	1	1	0
	90	0	2	3	2	0	0
	95	0	0	0	1	0	0
	NR	0	1	1	0	0	2

		Lying supine (*dB nHL*)					
		75	80	85	90	95	NR
Lying on right side (*dB nHL*)	75	0	0	0	0	0	0
	80	0	2	4	0	0	0
	85	0	3	6	2	0	0
	90	0	1	1	1	3	0
	95	0	0	1	1	1	0
	NR	1	0	2	0	0	1
Lying on left side (*dB nHL*)	75	1	0	0	0	0	0
	80	0	2	3	0	0	0
	85	0	3	7	2	0	0
	90	0	0	4	1	2	0
	95	0	0	0	1	0	0
	NR	0	1	0	0	2	1

		Lying on right side (*dB nHL*)					
		75	80	85	90	95	NR
Lying on left side (*dB nHL*)	75	0	0	0	0	0	1
	80	0	3	2	0	0	0
	85	0	1	9	2	0	1
	90	0	1	1	2	2	1
	95	0	0	0	0	1	0
	NR	0	1	0	2	0	1