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NORMATIVE DATA STUDY ON VESTIBULAR EVOKED MYOGENIC POTENTIAL

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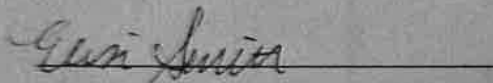
This is to certify that the thesis prepared by Tin Truong B.A. Au.D. Candidate, entitled Normative Data Study on Vestibular Evoked Myogenic Potential has been approved by the thesis committee as satisfactorily completing the thesis requirements for the degree Doctor of Audiology (Au.D.).



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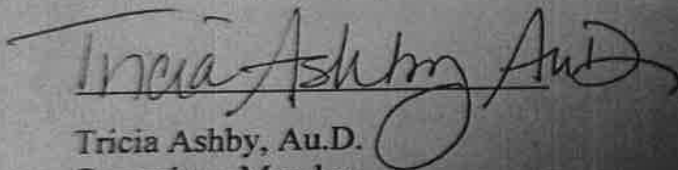
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ABSTRACT

A Normative Study on Vestibular Evoked Myogenic Potential

Tin Truong

Vestibular evoked myogenic potential is a specialized test within the vestibular test battery that specifically examines the integrity of the otolithic organs within the inner ear. The way in which the test is executed varies between individual clinics. Therefore, it is important for each individual clinic to establish its own set of normative data that are unique to their chosen recording and stimulus parameters. The goal of this current study is to establish normative data for cervical and ocular vestibular myogenic evoked potential tests at the Towson University Hearing and Balance clinic.

TABLE OF CONTENTS

	Page
I. LIST OF FIGURES	viii
II. LIST OF TABLES	ix
III. KEY TO ABBREVIATIONS	x
IV. CHAPTER 1: INTRODUCTION.....	1
V. CHAPTER 2: REVIEW OF THE LITERATURE.....	3
Anatomy	3
Introduction to the Vestibular Evoked Myogenic Potential	4
Response Indices	6
Threshold	9
Latency	9
Amplitude	10
Interaural Asymmetry Ratio	10
N1 Interaural Latency Difference.....	11
Stimulus Parameters	11
Stimulus Intensity	11
Stimulus Type.....	12
Stimulus Frequency	13
Stimulus Rate, Analysis Window, Filter Settings, Average Sweeps, Gain.....	14
Monoaural vs. Binaural Recordings	16
Electrode Montage.....	17
Subject Factors	18
Subject State	18

	Electromyography level.....	18
	Age and Gender.....	19
	Hearing Status	20
	Clinical Applications	20
	Goal of Current Study	23
VI.	CHAPTER 3: METHODOLOGY.....	24
	Participants	24
	Equipment.....	25
	cVEMP Protocol.....	26
	oVEMP Protocol	27
	Response Measurements	27
VII.	CHAPTER 4: RESULTS	29
	cVEMP Results	30
	oVEMP Results	33
VIII.	CHAPTER 5: DISCUSSION	36
	cVEMP	36
	oVEMP	40
	Conclusions	43
IX.	APPENDICES	45
	Appendix A: cVEMP Normative Data Table.....	45
	Appendix B: oVEMP Normative Data Table.....	46
	Appendix C: Fitness Level Categories	47
	Appendix D: Queens Step Test Directions.....	48

Appendix E: Informed Consent Form	50
Appendix F: Vestibular Testing Questionnaires	51
Appendix G: Vestibular Testing Instructions	52
Appendix H: IRB Approval.....	53
X. REFERENCES	54
XI. CURRICULUM VITA	62

LIST OF FIGURES

Figure 1. A cervical vestibular evoked myogenic potential waveform.....7

Figure 2. An ocular vestibular evoked myogenic potential waveform.....8

LIST OF TABLES

Table 1. Stimulus intensity from various studies.....	12
Table 2. Filter settings from various studies.....	15
Table 3. Number of averaging from various studies	15
Table 4. Mean age and VO ₂ max values for male and female participants	29
Table 5. Comparison of mean response indices of cVEMP between gender groups	32
Table 6. Comparison of mean response indices of oVEMP between gender groups	35

KEY TO ABBREVIATIONS

ANOVA: Analysis of Variance
ANSI: American National Standards Institute
cVEMP: Cervical Vestibular Evoked Myogenic Potential
dB: Decibel
EMG: Electromyography
ER-3A: Etymotic Research 3A
GSI-61: Grason Stadler Instrument-61
Hz: Hertz
oVEMP: Ocular Vestibular Evoked Myogenic Potential
SCC: Semicircular Canal
SCM: Sternocleidomastoid
TU-HBC: Towson University Hearing and Balance Center
VEMP: Vestibular Evoked Myogenic Potential
VO₂MAX: Maximal Oxygen Consumption

CHAPTER 1

INTRODUCTION

One of the earliest documentations of the Vestibular Evoked Myogenic Response (VEMP), a neurophysiological technique that is used to assess the function of the otolithic organs, can be traced back to the mid-1960s in a study spearheaded by Dr. Thane and his colleagues (as cited in McCaslin & Piker, 2011). They evoked a potential with an active electrode placed at the occipital protuberance in response to high intensity click stimulation to the ears. This sound-evoked muscle reflex that was hypothesized to originate from the peripheral vestibular system was dubbed as the vestibular evoked myogenic potential. Despite the excitement that surrounded the discovery of this potential, it was not until thirty years later that the VEMP became clinically useful (McCaslin & Piker, 2011).

Colebatch, Halmagyi, and Skuse (1994) were some of the first researchers to publish findings about the VEMP, specifically a style of VEMP that was recordable from the sternocleidomastoid muscle (SCM) that later became known as cervical VEMP (cVEMP). Around the same time frame, the ocular VEMP (oVEMP) was revealed at the XXIII International Congress of Barany Society as a response recorded from an electrode placed underneath the eyes in response to a high intensity click stimulation to the ears. Similar to cVEMP, oVEMP quickly found a niche in the vestibular test battery thanks to its unique ability to assess the integrity of the otolithic organs in the vestibular system (McCaslin & Piker, 2011).

VEMP tests are unique in that they are the only diagnostic tests within the vestibular test battery that exclusively assess the integrity of the otolith organs. Other tests focus on other regions; for example, the VOR test is limited to the assessment of the semicircular canals, while

ENG and caloric tests are limited to assessment of horizontal semicircular canal function. These tests may indirectly assess the otolith organs since the vestibular organ is a connected network, but the otolith organs are not the primary focus of these tests.

The manners in which VEMP tests are performed are highly variable in different clinical settings. Therefore, it is important for each individual clinic to establish its own set of normative data that are unique to their chosen recording and stimulus parameters. The goal of this study is to establish normative data for cVEMP and oVEMP tests at the Towson University Hearing and Balance clinic. This is an important first step to integrating VEMP testing into the existing vestibular test battery.

CHAPTER 2

LITERATURE REVIEW

Anatomy

Within the petrous portion of the temporal bone lie the peripheral auditory system and the peripheral vestibular system. The auditory system is responsible for hearing while the vestibular system is responsible for balance and spatial acceleration. The information that the peripheral vestibular system obtains, in conjunction with information from the visual and somatosensory systems, assists in the maintenance of an individual's equilibrium and position in space.

The peripheral vestibular system is comprised of three semicircular canals (SCC) and two otolithic organs in each ear. The SCCs are oriented in three different planes of space, at 90-degree angles relative to each other. The SCCs are responsible for sending angular acceleration information, such as rotation of the head in the roll, pitch and yaw angles to the brain. Connected to the base of the SCCs are the saccule and the utricle, two otolith organs responsible for detecting linear acceleration of the head in the horizontal or vertical planes. The utricle is oriented in the horizontal plane and it responds to linear acceleration in the horizontal plane, whereas the saccule is oriented in the vertical plane and it responds to linear acceleration in the vertical plane. Together, these otolith organs provide information to the brain regarding gravitational pull. As a whole, the SCC and the otolith organs are responsible for sending information to the brain and aiding the brain in detecting angular and linear motion of the head and body in space.

Introduction to the Vestibular Evoked Myogenic Potential

The vestibular evoked myogenic potential (VEMP) is a muscle reflex that is evoked by loud sounds. Historically, this response has been recorded from various muscles such as the trapezius, triceps, soleus, and gastrocnemius muscles (Jacobson et al., 2011). In the majority of audiologic clinical and research settings, however, VEMPs are mostly recorded from cervical and infraorbital locations (Jacobson et al., 2011). The VEMP is unique in that it is the only test in the vestibular test battery that assesses the integrity of the otolith organs.

Cervical VEMP (cVEMP) is an ipsilateral response that reflects an electrophysiological manifestation of the vestibule-colic reflex, which is one that is responsible for stabilizing head position in space (Jacobson et al., 2011). It is independent of cochlear status since it is present in patients with sensorineural hearing loss (SNHL), and absent in patients who have undergone selective vestibular neurectomy Al-Sebeih and Zeitouni (2002). The cVEMP primarily arises from the saccule.

The vestibular portion of the VIII nerve innervates the saccule. Jacobson et al. (2011) noted that the vestibular portion of the VIII nerve bifurcates into superior and inferior sections; the superior section receives activity from the anterior portion of the saccular maculae whereas the inferior portion receives activity from the posterior portion of the saccular maculae. The inferior portion is the primary neural generator of the cVEMP response. When the saccule is stimulated by sound, the vestibulocochlear cranial nerve (VIII nerve) is activated via the afferent system. This neural response descends via the vestibulospinal tract to the accessory cranial nerve (XI), which innervates the sternocleidomastoid muscle of the neck (Jacobson et al., 2011). The

synapse at the level of the SCM muscle creates an inhibitory biphasic myogenic response that can be recorded from the SCM in a tonic state (Colebatch & Rothwell, 2004).

Ocular VEMP (oVEMP) is an electrophysiological manifestation of the vestibulo-ocular reflex, which is a reflex responsible for stabilizing the image on the center of the visual field by producing an eye movement opposite of the head movement (Piker et al., 2001). Literature has suggested that oVEMP primarily arises from the utricle. Similar to the saccule, the utricle is innervated by the vestibular portion of the VIII nerve. However, it is the superior portion of the vestibular nerve that is the primary neural generator of oVEMP responses. This neural pathway ascends via the medial longitudinal fasciculus to the oculomotor nerve (CN III), which innervates the inferior oblique muscle. The synapse at the level of this muscle creates an inhibitory bilateral myogenic response that can be recorded from below the contralateral eye muscle in a tonic state when the gaze is directed upward (Piker et al., 2001). However, the peripheral origin of the oVEMP is a controversial topic in vestibular literature. There is compelling evidence suggesting that the cVEMP and the oVEMP arise from different parts of the vestibular system. However, there is also literature suggesting that oVEMP represents a response from the utricle, utricle and saccule, or saccular afferents in the superior vestibular nerve (Welgampola & Colebatch, 2001)

VEMP can be a valuable addition to the vestibular test battery, as the existing diagnostic tests do not provide enough insight about the otolith organs and their pathways. These pathways are not the primary focus of many vestibular tests. For example, electronystagmography (ENG) testing and rotation chair testing primarily evaluate the semicircular canals and their pathways in relation to oculomotor activity. Due to the unique nature of VEMP testing, it can provide a unique glimpse into the integrity of the otolith organs as well as its afferent and efferent pathways.

Response Indices

Analysis of the VEMP involves evaluating the threshold of the response, latency, amplitude, interaural asymmetry ratio, and n1 interaural latency difference specifically for oVEMP. Figure 1 shows a sample cVEMP waveform, while Figure 2 shows a sample oVEMP waveform. Due to the similarity between cVEMP and oVEMP response indices, the following literature review will apply to both tests. Distinction between the two tests will be made when relevant.

Threshold

Many researchers have investigated VEMP thresholds for normal hearing subjects with no history of vestibular pathologies. Colebatch et al. (1994) have suggested that cVEMP thresholds fall within the 75-80 dB nHL range. Ochi, Ohashi and Nishino (2001) reported a slightly higher range of 87.78 dB nHL +/- 5.54, and Akin et al. (2003) reported an even higher range of 91 dB nHL +/- 5.2. In regards to oVEMP thresholds, it has been reported that threshold can range from 83 dB nHL to 118 dB nHL (Chihara et al., 2007; Park et al., 2010). Based on the reports from literature, for this present study, the participants' cVEMP thresholds were expected to be in the approximate range of 75-90 dB nHL, while oVEMP thresholds were expected to be in the approximate range of 80 – 118 dB nHL.

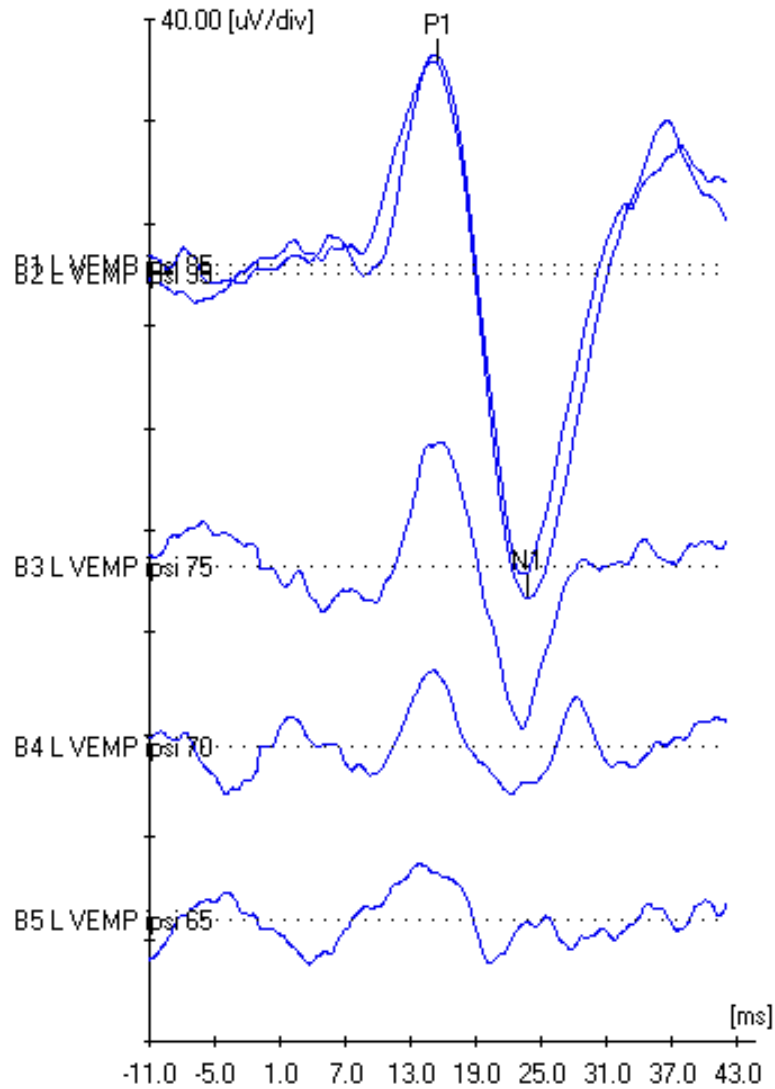


Figure 1. A biphasic cVEMP waveform in response to a 500 Hz air-conducted tone-burst sound showing initial positivity (p1) and negativity (n1). The cVEMP has a threshold of 70 dB nHL, with p1 latency at approximately 16 ms and n1 latency at approximately 23 ms.

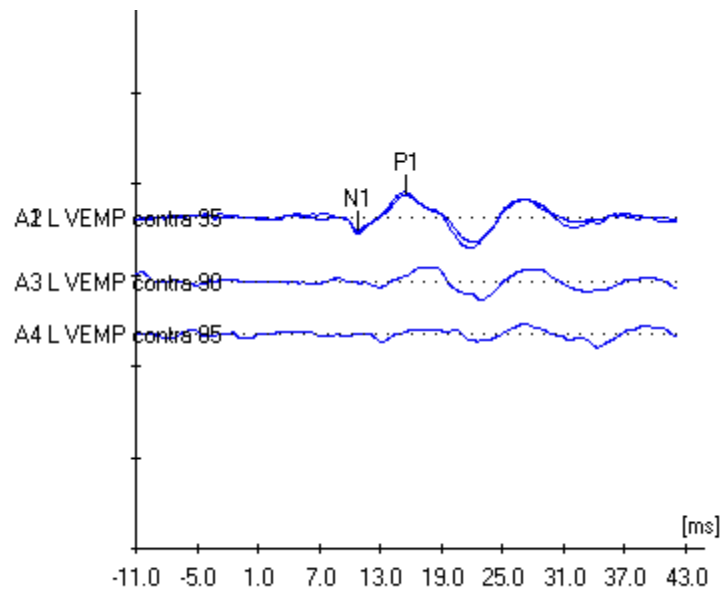


Figure 2. A biphasic oVEMP waveform in response to a 500 Hz air-conducted tone-burst sound showing initial negativity (n1) and positivity (p1). The oVEMP has a threshold of 90 dB nHL, with n1 latency at approximately 12 ms and p1 latency at approximately 16 ms.

Latency

Colebatch et al. (1994) were one of the first to describe the latencies of the VEMP response. The cVEMP waveform is comprised of two components labeled as “p1” (first positive wave) and “n1” (first negative wave), based on the polarity of the peak. These waveforms can also be referred to as “p13” and “n23” after the mean latencies at which they occur. Based on reports from the literature, for this present study, the peaks will be referred to as p1 and n1. In individuals with normal hearing status and no history of vestibular pathology, the mean latency for the p1 is 13.3 ms +/- 1.5 and the mean latency for the n1 is 22.6 ms +/- 2.4, in response to a click stimuli (Colebatch et al., 1994). To a tone burst stimuli, the latencies are slightly longer as the mean latency for the p1 is 16.1 ms +/- 2.1 and the mean latency for the n1 is 23.8 ms +/- 2.2. The latencies do not seem to be affected by presentation level (Akin, Murnane, & Proffitt, 2003; Lim, Clouston, & Sheehan, 1995), tonic level (Lim et al., 1995), or age (Wang et al., 2008).

The oVEMP waveform wave order is the reverse of cVEMP waveform, comprised of the n1 first then the p1. Piker et al. (2011) reported mean latencies for n1 to be 12.1 ms +/- 1.1 and mean latencies for p1 to be 17.1 ms +/- 1.3. Other researchers have reported the latencies to be 1 to 2 ms earlier than what Piker et al. reported (Chihara et al., 2007; Park et al., 2010; Wang et al., 2009; Welgampola et al., 2009).

Based on existing literature, the participants' cVEMP latency values for this study were expected to be in the approximate range of 13.3 ms +/- 1.5 for p1 and 22.6 ms +/- 2.4 for n1. Participants' oVEMP latency values are expected to be in the approximate range of 11 ms for n1 and 16 ms for p1.

Amplitude

VEMP amplitude measures are highly variable due to the response's dependency on stimulus intensity and muscle contraction level, which will be referred to as tonic EMG levels (Colebatch et al., 1994). Akin et al. (2003) reported that the cVEMP amplitude for p13-n23 ranged from 16-179 μV . Colebatch et al. (1994) similarly reported high variability in amplitude, with results ranging from 18.3-137.1 μV , even with normalized EMG level of 60 μV and a uniformed stimulus presentation at 95 dB nHL. oVEMP amplitudes are smaller and less variable than cVEMP amplitudes. Piker et al. reported oVEMP amplitude to be as low as 5.1 μV ($\pm 3.1 \mu\text{V}$) while others have reported higher amplitude values such as 6.5 μV ($\pm 2.9 \mu\text{V}$) (Wang et al., 2009), and 7 μV ($\pm 1 \mu\text{V}$) (Chihara et al., 2007). Based on reports from the literature, for this present study, the participants' VEMP amplitude responses were expected to be in the approximate range of 17-130 μV , and oVEMP amplitude responses were expected to be in the approximate range of 5-8 μV .

Interaural Asymmetry Ratio

Similar to auditory brainstem response testing, an interaural asymmetry ratio calculation is employed for VEMP testing to aid in differentiating a normal versus an abnormal VEMP response. The asymmetry ratio uses VEMP waveform amplitudes obtained from both SCM muscles of the participants to assist in identifying unilateral lesions that can affect the VEMP pathways. Due to the potential high variability in the amplitude of the response, this is an effective measure of the response as it allows the participants to be their own control. Interaural amplitude asymmetry ratio values were calculated using the following equation:

$$\text{ratio (\%)} = [(\text{AmpRight} - \text{AmpLeft}) / (\text{AmpRight} + \text{AmpLeft})] \times 100$$

N1 Interaural Latency Difference

A response index that is unique to oVEMP is the n1 interaural latency difference. This value has been reported to be between .5 ms to .8 ms (Piker et al., 2009; Piker et al., 2011).

Therefore, oVEMP n1 interaural latency difference was expected to be in this range.

Stimulus parameters

This section of the literature review will focus on the stimulus and recording parameters that were used to collect normative data for the clinic, as well as the rationalization behind choosing these parameters based on evidence from the literature. The stimulus parameter indices for cVEMP and oVEMP are similar; therefore, the following literature review will apply to both measures. Distinction between the two tests will be made when relevant.

Stimulus Intensity

Vestibular evoked myogenic response is a response to an intense sound (90 – 105 dB nHL). Akin et al. (2003) conducted a study to examine the effect of stimulus intensity on latency, amplitude, and threshold of the VEMP in normal hearing subjects with no history of vestibular disease. They concluded that the response amplitude of the VEMP increased linearly with increasing stimulus intensity, while VEMP latency was not influenced by stimulus level (Akin et al. 2003). Colebatch et al. (1994) reported similar findings in a VEMP study where normal hearing subjects with no history of vestibular diseases were presented three to five different stimulus intensities. They found that the response amplitude increased along with the stimulus intensity, and that an amplitude response to a 100 dB nHL click was 36% larger than an

amplitude response to a 95 dB nHL click (Colebatch et al., 2004). This is consistent with Lim et al.'s (1995) findings that an amplitude response to a 100 dB nHL click was 30% larger than an amplitude response to a 95 dB nHL click. In the majority of VEMP studies, the stimulus intensity has hovered between 95 dB nHL and 100 dB nHL. For this present study, the investigators have chosen to use 95 dB nHL as the stimulus intensity.

Table 1

Stimulus intensity in various studies

<i>VEMP studies</i>	<i>Stimulus Intensity</i>
Kelsch et al. (2010)	90 dB nHL
Cheng (2003)	95 dB nHL
Wang et al. (2004)	105 dB nHL
Welgapola & Colebatch (2001)	100 dB nHL

Stimulus Type

VEMP responses can be evoked using tone burst and click stimuli. Numerous studies have compared both types of stimuli in order to determine the optimal presentation stimulus, and the final conclusions from these studies are variable. Wu et al. (2007) compared VEMP responses evoked by tone bursts and clicks in 22 normal hearing individuals with no history of vestibular disease. They found that while VEMP responses were present in all subjects, tone burst stimuli elicited significantly longer latencies and greater amplitudes. They concluded that, due to the significant variability between VEMP responses to tone burst and click stimuli, different normative data for each of the stimuli should be established for clinical interpretations.

Overall, they recommended using tone burst stimuli because latencies and amplitudes for clicks were different across several labs, including theirs (Wu et al., 2007). Support for using tone bursts over click stimuli is found in older literature as well. Akin et al. (2003) found that VEMP amplitude was larger for 500 Hz tone bursts than for clicks, and Welgampola and Colebatch (2001) found that tone bursts required lower stimulus level than clicks to produce similar VEMP amplitudes. However, Cheng et al. (2003) found that, in 29 normal hearing subjects, clicks elicited higher response rate, shorter latency, and larger amplitude compared to those elicited by tone bursts. Akin et al. (2003) attributed these contradictory findings to differences in varied calibration standards across experiments. The type of stimulus is variable in literature as many experiments use tone bursts (Kerdsiri, 2010; Janky, 2009; Wang, 2004) as well as clicks (Brantberg & Fransson, 2001; Cheng et al., 2003; Welgampola et al. 2001). For the present study, investigators chose to use toneburst stimuli.

Stimulus Frequency

VEMP responses can be recorded at different stimulus frequencies. Akin et al. (2003) reported that most subjects had VEMPs present at 500 Hz, 750 Hz, and 1000 Hz while few subjects had VEMPs present at 2000 Hz. Murofushi et al. (1999) compared myogenic potentials on the SCM evoked by three different toneburst frequencies, 500 Hz, 1000 Hz, and 2000 Hz. They found that 500 Hz tonebursts elicited the greatest response in every subject while 2000 Hz toneburst elicited the smallest. Welgampola and Colebatch (2001) also reported that tone burst evoked responses showed largest amplitudes at 500 Hz or 1000 Hz. An optimal frequency stimulus has also been reported at 300 Hz (Tood et al., 2000). These results are consistent with McCue and Guinnan's (1997) findings in animals that sound sensitive vestibular afferents showed a broad, V-shaped tuning curve with best frequencies between 500 Hz and 1000 Hz, and

no responses above 3000 Hz. For the present study, investigators chose to use 500 Hz as the frequency stimulus.

Stimulus Rate, Analysis Window, Filter Settings, Average Sweeps, Gain

Compared to other VEMP stimulus parameters, stimulus rate has not been extensively studied. Murofushi (1999) conducted a study on 12 normal adults at different stimulus rates (1 Hz, 5 Hz, 10 Hz, 15 Hz, and 20 Hz). He found amplitude was higher at 1 Hz and 5 Hz, and progressively decreasing as the stimulation rates increased. This is evident as no response was seen at 15 Hz in one ear, and no response was seen at 20 Hz in nine ears. Stimulus rate was reported to have no effect on latency in this study. He concluded that a lower stimulation rate generated a more robust response. He also recommended the 5 Hz stimuli over 1 Hz stimulus due to its advantage of having shorter examination time without giving up better signal averaging ability. For the present study, investigators chose to use 5 Hz repetition rate.

The dominant energy spectrum of an EMG signal is found between 40 Hz and 150 Hz (Akin & Murnane, 2008), therefore the filter setting should have a high pass cutoff of approximately 5-20 Hz and a low pass cutoff of approximately 1000-2000 Hz (Akin & Murnane, 2008). Different studies have used different EMG filter settings. For the present study, investigators chose to use the 10-1500 Hz filter setting.

Table 2

Filter settings in various studies

<i>VEMP studies</i>	<i>Filter Settings</i>
Sheykholeslami et al. (2001)	20 Hz – 2000 Hz
Ferber-Viart et al. (1997)	8 Hz – 1600 Hz
Colebatch et al. (1994)	8 Hz – 1600 Hz
Welgapola & Colebatch (2001)	8 Hz – 1600 Hz

The VEMP response is reported to be more robust than an ABR response, therefore accurate results can be obtained from a fewer number of signals (Akin & Murnane, 2008). Different studies have used different EMG filter settings. For the present study, we chose 120 as our max number of averages.

Table 3

Number of averaging in various studies

<i>VEMP studies</i>	<i>Averaging</i>
Sheykholeslami et al. (2001)	200 ms
Akin et al. (2003)	128 ms
Colebatch et al. (1994)	124 ms
Welgapola & Colebatch (2001)	256 ms

Colebatch et al. (1994) noted that the VEMP response is complete at approximately 25 ms; therefore, our analysis window is set at 60 ms in order to capture the complete response. In regard to amplifier gain setting, McCaslin and Piker (2011) recommended an amplifier gain setting of 5000 for cVEMP, and 100,000 for oVEMP.

Monaural vs. Binaural Recordings

Murofushi, Takai, Iwasaki and Matsuzaki (2005) conducted a study to compare VEMP response characteristics between binaural and monaural recording conditions. Results from 28 adult subjects showed that there were no statistical differences in the results obtained from both conditions. Different researchers have replicated this study and reported similar findings (Bhagat, 2006; Ozdek, Metin & Korkmaz, 2010; Wang & Young, 2003). These results suggest that the methods of recording VEMPs do not affect the overall response measures. The primary advantage that a binaural recording condition has over a monaural recording condition is shorter test time. Due to simultaneous presentation of the stimuli, the test time is theoretically halved. Shorter test time also means the participants have to contract their muscles for a shorter duration; this reduces the risk of muscle fatigue over time. Muscle fatigue may be an important factor when testing special populations that may have trouble achieving sufficient muscle contraction over an extended time period. The primary disadvantage to a binaural recording that is unseen in a monaural recording is contamination of artifact due to midline crossover (Li et al., 1999). In contrast to the previous studies that suggested that there are no significant differences between a binaural and monaural recording condition, a study conducted by McGrath (2010) showed that simultaneous binaural recording condition is not as accurate as monaural recording condition. This is due to myogenic and other evoked potentials crossing over from the stimulated ear to the

opposite side sternocleidomastoid muscle (McGrath, 2010). In this study, the current investigators have chosen to record VEMPs monaurally.

Electrode montage

Several investigators have examined the location of the active electrode site for VEMP recording. Placement of the electrodes is vital for obtaining a robust response. In regard to cVEMP recordings, there are varying suggestions on the optimal site of placement in the literature. Ferber-Viart et al. (1997) first recommended recording from the trapezius muscle. However, they found that VEMPs recorded from the trapezius muscle have significantly longer latencies and greater amplitude compared to VEMPs recorded from the SCM. This method was quickly abandoned as they theorized that these significant differences might be due to the possibility that signals other than the intended signal were being measured (Ferber-Viart et al., 1997). Sheykholeslami, Murofushi, and Kaga (2001) conducted an experiment to find the optimal location on the SCM for electrode placement. Out of the four different locations over the SCM muscle (the upper part of the SCM muscle at the level of mandibular angle, the middle part of the muscle, and immediately above sternal and clavicular origins of the SCM muscle), they found that the upper part of the muscle gave the response with the highest amplitude, while the middle part of the muscle gave the most consistent responses (Sheykholeslami, Murofushi & Kaga, 2001). For this current study, the investigators have chosen the middle part of the SCM as the site of active electrode placement, the sternoclavicular joint as the inverting electrode, and the forehead as ground for cVEMP. For oVEMP, the active electrode placement is immediately underneath the eyes, the inverting electrode is on the chin or the nose, and the forehead as ground.

Subject factors

Similar to other electrophysiological tests, individual subject factors have a considerable impact on obtaining accurate cVEMP and oVEMP recordings. In this section, we will discuss varying subject factors such as subject state, EMG level, age, gender, and hearing status.

Subject State

For cVEMP recordings, the participant is required to keep the SCM muscle contracted for responses to be measured; similarly for oVEMP testing, the subject is required to gaze upward in order to contract the inferior oblique muscle. Because recording the VEMP is heavily reliant on the cooperation of the subject, the subject is required to be conscious and attentive during testing.

Electromyography level

Akin et al. (2004) highly recommended controlling the tonic electromyography (EMG) level, also known as muscle tonic level, in subjects due to high inter-subject variability rate. They reported that the muscle tonic level had a significant impact on the response amplitude. VEMP amplitude increases as the muscle tonic level increases (Akin et al. 2004). Optimal EMG level is highly debated in the existing literature. Investigators have recommended keeping the EMG level at 30 to 50 μV , some have suggested EMG level even as high as 60 μV (Akin et al., 2003; Akin et al., 2004; Colebatch et al. 1994).

There are several methods of normalizing and tracking tonic EMG level across subjects in the literature. A traditional way of obtaining a VEMP is simply asking the subjects to turn their heads away from the ear in which they hear the stimulus (Akin et al., 2004). Colebatch et al. (1994) have also successfully obtained VEMPs by asking their subjects to press their forehead

against a bar in front of them, as well as asking the subjects to lift their head against gravity while in a supine position. There are also several methods to tracking tonic EMG level. One method makes use of a commercial EMG tracking system that tracks the subject's level of muscle contraction via an electrode attached at the muscle (Akin et al., 2004). Vanspauwen, Wuyts, and Van de Heyning (2006) reported tracking EMG level by using a blood pressure nanometer and asking subjects to press their chin up against the pad. In settings where these commercial systems are not readily available, there are also ways to normalize and track EMG level. One way to monitor EMG level without a machine is by instructing the subjects to hold a tennis ball between their chin and their chest while the clinician provides visual feedback (Davenport, 2010). Although this is more subjective in comparison to the methods previously listed, it is a practical and inexpensive alternative that can normalize EMG level by making the contractions from each muscle as symmetrical as possible. For this study, this is the method that the investigators used.

Age and Gender

Castelein, Deggouj, Wuyts, Gersdorff (2008) indicated that in normal hearing subjects without any history of vestibular pathology, cVEMP responses are present under the age of 60 regardless of the gender. However, in subjects over 60 years of age, the cVEMP response prevalence decreases approximately 25-30% per decade (Castelein et al. 2008). Similarly, in a study by Piker et al. (2011), the oVEMP response can only be generated in 77% of subjects over 50 years old compared to 100% in subjects less than 50 years of age. The changes in these recordings are seen in the amplitude of the response as well as the latencies of the responses. In a study that evaluated age-related VEMP changes, Brantberg, Granath and Scharf (2007) reported that VEMP amplitude decreases, while VEMP latencies increase with age; it is speculated that

these changes may be due to age-related structural changes within the middle ear. Nguyen, Welgampola, Carey (2010) reported similar findings, where they found that cVEMP, amplitudes were significantly lower in subjects older than 50 years of age; the amplitude changes were reported to be even more significant in oVEMP recordings. The subjects recruited for this study were limited to young adults between the ages of 18-30 years old, therefore age-related effects on our VEMP recordings were considered to be irrelevant.

Hearing Status

Similar to other electrophysiologic testing, a conductive hearing loss can compromise VEMP recordings. Bath, Harris and McEwan (1999) evaluated the effects of conductive hearing loss on VEMP recordings. They found air-bone gaps between 9-40 dB HL could result in absent VEMP responses. VEMP thresholds were reported to be higher in these subjects due to reduced stimulation as a product of the conductive hearing loss (Bath et al., 1999). Unlike conductive hearing loss, a sensorineural hearing loss that did not result from VIII nerve damage has no effect on VEMP recordings (Castelein et al, 2008). Castelein et al (2008) as well as Al-Sebeih and Zeitouni (2002) showed that VEMP is found in patients with SNHL and absent in patients who have undergone selective vestibular neurectomy. Due to these factors, any participants whose audiometric results did not indicate normal hearing status and normal tympanometry bilaterally were excluded from this study.

Clinical Applications

Superior semicircular canal dehiscence syndrome (SSCD) is a syndrome that can arise from the failure of postnatal bone development of the thin bone that overlies the superior canal that may later be disrupted by pressure or trauma to the temporal lobe (Minor, 2005). The

diagnosis is often made based on temporal bone high resolution computed tomographic scans and symptoms typically expressed by patients (Pfammatter, et al., 2010). Due to the dehiscence creating a third mobile window into the inner ear, the superior semicircular canal becomes more sensitive to sound and pressure stimuli resulting in vertigo induced by loud noises, also known as Tullio's phenomenon (Minor, 2005). In patients with SSCD, VEMP potentials tend to have reduced thresholds. Minor (2005) conducted a study on VEMP thresholds on 51 ears with SSCD, 30 patients with unilateral SSCD, and 30 patients who had undergone VEMP testing with no symptoms suggestive of SSCD. They found that affected ears had a mean threshold of 81 +/- 9 dB nHL, whereas threshold for unaffected ears was 99 +/- 7 dB nHL and for control ears was 98 +/- 4 dB nHL. Pfammatter et al., (2010) indicated there is a negative linear relationship between VEMPs and the size of the SSCD. Patients with a dehiscence size of 2.5 mm or greater had significantly lower VEMP threshold than patients with a dehiscence size below 2.5 mm. This may be attributed to the increased effectiveness of sound transmission to the saccule caused by increased compliance of the inner ear.

The VEMP is also clinically relevant in evaluating for Meniere's disease due to its unique ability to assess the integrity of the vestibule-collic pathways. Meniere's Disease is an inner ear pathology that can cause atrophy to the saccule (Welgampola & Colebatch, 2005). It is trademarked by symptoms such as tinnitus, episodic rotatory vertigo, low frequency hearing loss that can fluctuate depending on the severity of the disease, and aural fullness (Rauch, Zhou, Kuwaja, Guinan & Herrmann, 2004). In patients with Meniere's disease, VEMP can be absent, thresholds can decrease, and VEMP frequency tuning can be altered (Akin & Murnane, 2008). Interaural asymmetry ratio was suggested to be the most sensitive VEMP measure in diagnosing Meniere's disease unilaterally. Murofushi, Shimizu, Takegoshi and Cheng (2001) and Young et

al. (2003) reported that as Meniere's disease progresses, the more the interaural asymmetry ratio increases. The dilation of the saccular membrane in the pathologic ear due to increased endolymph fluid causes the saccule to be hypersensitive to sound, which causes the VEMP amplitude to greatly increase (Young et al. 2003).

Due to the unique pathways that can be evaluated by VEMP testing, VEMP can be clinically relevant in aiding the diagnoses of a variety of pathologies. VEMP can also be used to detect vestibulospinal lesions in patients with multiple sclerosis. Due to demyelination in primary afferent axons or secondary vestibulospinal tract axons, VEMP latencies in these patients can be prolonged (Shimizu et al., 2000). Because VEMP testing assesses the sacculo-collic reflex, which descends via the lower brainstem, it can see clinical use in evaluating vestibular integrity in patients with a brainstem stroke (Chen & Young, 2003). In patients with a tumor at the cerebellopontine angle, VEMP can also be used to pinpoint the location of the tumor on the vestibular nerve. This can be performed preoperatively in order to predict the site of lesion and plan the surgical approach. VEMPs can also be performed post-operation in order to assess residual function of the nerve (Chen & Young, 2002). Colebatch and Rothwell (2004) mentioned that VEMP could be used clinically in patients with basilar type migraine. This is a type of migraine that is characterized by neurological signs to the brainstem, cerebellum, or occipital cortex. VEMPS in these patients can be delayed or completely absent due to the interruption in the descending pathway from the saccule through the brainstem to the XI cranial nerve (Colebatch & Rothwell, 2004).

Goal of the Current Study

Although normative data for cVEMP and oVEMP are abundant in the literature, it is unwise to apply these normative data to current TU-HBC VEMP diagnostic tests. Based on the literature review, it is clear that there is high variability in stimulus and recording parameters across different researchers. Because different clinics use different protocols to record VEMP, it is vital for individual clinics to establish its own normative data under its own protocol to make sure that comparisons are made under the appropriate test conditions. This was designed to first establish normative data for cVEMP and oVEMP at the Towson University Hearing and Balance Center. Secondly, it was also designed to examine any potential difference between gender groups and VEMP values. Finally, there is no current evidence in literature examining the correlation between an individual's cardiorespiratory fitness and their vestibular functions. Therefore, the final goal of this study was to determine if an individual's fitness level affect their cVEMP and oVEMP values.

CHAPTER 3

METHODOLOGY

Participants

Thirty participants between the ages of 20-26 years old (13 males and 17 females) participated in this study. Participation in the study was voluntary and informed consent was obtained from all individuals in compliance with Towson University's policy on the International Review Board (IRB) to protect human subjects. A copy of the IRB approval is included in Appendix H.

Exclusion criteria for all participants included complaints of dizziness or imbalance, known otologic disease, neurologic disease, conductive hearing loss, or disease affecting the cervical vertebrae or spinal cord, air-bone gap greater than 10 dB at any frequency from 500-4000 Hz. To rule out audiologic/vestibular disorders, a comprehensive case history questionnaire was mailed to the participants and completed prior to testing (see Appendix F and G for the questionnaires), and audiological evaluation was performed on each participant prior to testing. This included otoscopy, immitance testing, pure tone testing, and speech testing.

Normal hearing was defined as an air puretone threshold at or above 15 dB SPL at octave frequencies from 250 to 8000 Hz with no air-bone gaps greater than 10 dB SPL. Normal middle ear status was defined as a Jerger Type A tympanogram bilaterally, peak pressure values between +/- 149 daPa, static compliance values between 0.3 and 1.4 ml, and ear canal volumes between 0.5 and 1.6 ml (Jerger, 1970).

Participants' fitness level was also assessed in this study in order to examine the potential effect fitness level has on VEMP responses. Cardiorespiratory fitness level was evaluated through the Queens Step test (see Appendix D) in which the participants were instructed to step on and off a step for three minutes. Active heart rate was taken at 3 minutes and 20 seconds with a pulse oximeter, and VO₂max values and categorical fitness levels were derived from these data.

Equipment

All testing was performed in an Industrial Acoustic Company (IAC) double walled audiometric booth. A GSI-61 clinical audiometer was used to assess pure tone thresholds; a GSI Tymstar immittance bridge was used to verify normal middle ear function. Both the audiometer and immittance bridge were calibrated according to ANSI standards on August 23, 2014. Pure tone air conduction testing was measured via Etymotic Research (ER)-3A insert headphones. A commercial BioLogic evoked potential system was used for VEMP testing. The stimulus was a 500 Hz Blackman-gated tone burst with a 2 ms rise/fall time with 0 ms plateau time presented at the rate of 5/sec. The stimuli were presented monaurally through etymotic ER-3A insert headphones. One hundred and twenty sweeps were averaged for each trial. EMG signals were amplified 5000 times for cVEMP, and 100,000 times for oVEMP. Bandpass filtered was set at 10-1500 Hz. Artifact rejection was disabled.

Both cVEMP and oVEMP were recorded using a two-channel montage. Gold cup recording electrodes, conductive paste and medical tape were used to obtain VEMP recordings. Electrode sites were scrubbed with alcohol wipes and NuPrep skin paste prior to electrode placement. For cVEMP recordings, the electrode montage consisted of non-inverting electrodes placed on the upper 1/3 portion of both SCM muscles, reference electrode on the sternum or

sternoclavicular joint, and ground electrode on the forehead. For oVEMP recordings, the electrode montage consisted of ground electrode on the forehead, non-inverting electrodes placed directly underneath the lower eyelid, and reference electrode on the chin. If there were subject factors that did not allow for electrode placement on the chin such as facial hair, an acceptable alternative placement for the reference electrode was on the nose. Electrode impedances were kept at or below 3000 Ohms.

cVEMP protocol

To perform a cVEMP, participants were seated in a comfortable chair facing forward for testing. They were instructed to lift their head, turn away as far as they can from the tested ear, and clamp a tennis ball between their chin and shoulder when they hear the stimulus. When they cease to hear the stimulus, they were instructed to remove the tennis ball, then return to resting position facing forward and relaxed. In order to obtain participant data for supra-threshold levels, participants were first presented with a 95 dB nHL toneburst stimulus. If no response was recorded at that level, the recording session was terminated, and an absent response for that ear was entered into the participant's database. Tracings were replicated twice to ensure replicability of the response at this level. In order to estimate participant threshold, the "down 10 up 5" procedure was performed starting at 95 dB nHL. Tracings at threshold were also repeated twice to ensure replicability of the response. Once supra-threshold and threshold levels were obtained, the same procedure was repeated on the opposite ear. The test order of the left and right side was randomized.

oVEMP protocol

To perform an oVEMP, participants were seated in a comfortable chair with head facing forward at a midline in a relaxed position. When the stimulus started, the participant was instructed to gaze upward 30 degrees without moving the head or neck and return gaze to resting position when the stimulus stopped. If the participants showed a weak oVEMP response or if they did not have recordable oVEMP responses, then they were instructed to direct their gaze maximally upward. In order to obtain data for supra-threshold levels, participants were first presented with a 95 dB nHL toneburst stimulus. If no response was recorded at that level, the recording session was terminated, and an absent response for that ear was entered into the participant's database. Tracings were replicated twice to ensure replicability of the response at this level. In order to estimate participant threshold, the "down 10 up 5" procedure was performed starting at 95 dB nHL. Tracings at threshold were also repeated twice to ensure replicability of the response. Once supra-threshold and threshold levels were obtained, the same procedure was repeated on the opposite ear. The test order of the left and right side was randomized.

Response measurements

The VEMP response indices that were taken into consideration were the absolute latency of waves p13 and n23, the peak-to-peak amplitude values of p13-n23, and the interaural asymmetry ratio values for amplitude. Interaural asymmetry ratio (AIDR) amplitude values were calculated using the following equation:

$$\text{IADR (\%)} = [(\text{AmpRight} - \text{AmpLeft}) / (\text{AmpRight} + \text{AmpLeft})] \times 100$$

N1 interaural latency difference is a response value that is unique to oVEMPs. The n1 interaural latency values were calculated using the absolute value of the difference between left and right oVEMP n1 latencies

CHAPTER 4

RESULTS

Table 5 shows the mean age and VO₂max values for all participants. The table below displays the range and mean ages of both gender groups, the range and mean VO₂max values, as well as the population percentile the VO₂max value of each gender. There were 13 male participants, 17 female participants with their age ranging from 20 to 26 years old. Male VO₂max values were in the 80th percentile, while female VO₂max values were in the 55th percentile. It appears that male participants tend to be more athletic than the female participants in this study.

Table 4.

Mean Age and VO₂max Values for Male and Female Participants.

Participants	Age			VO ₂ max		
	N	M (SD)	Range	N	M (SD)	Range
Male	13	23.23 (1.88)	20-26	12	51.79 (9.77) (80 th %)	39.93-60.93
Female	17	23.5 (1.62)	20-26	16	38.71 (9.69) (55 th %)	32.56-46.97
Total	30	23.39 (1.71)		29	45.25 (9.36)	

Note. VO₂max was previously designed for gender differences. Men: VO₂max = 111.33 – (0.42 x HR); Women: VO₂max = 65.81 – (.1847 x HR). HR = heart rate @ 3 minutes and 20 seconds.

CVEMP Results

Descriptive statistics of cVEMP parameters for male and female participants, as well as the total of male and female participants are shown in Table 6. The table includes the mean and one standard deviation for cVEMP response indices; the table also includes results obtained from the independent t-test used to examine the potential cVEMP response differences between gender groups. In general, threshold, and latency values between male and female appears to be similar to each other; however, male amplitude values appear to be larger than female amplitude values.

A Kolmogorov-Smirnov test was conducted to determine possible violation of the assumption of normality. Latency values, amplitude values, and interaural amplitude asymmetry were normally distributed, however, the assumption of normality was violated for threshold values, as it was not normally distributed. In order to examine if this affected the outcome of the inferential statistical analysis described in this section, parallel non-parametric tests were conducted and compared to the parametric tests. None of the outcomes changed in terms of statistical significance. As a result, the conclusions made based on the parametric tests were assumed to be valid regardless of the non-normal distribution of the threshold values. The Levene's test was performed and results indicated homogeneity of variance between gender groups. An independent sample t-test was performed to examine the difference between male and female participants for right ($t(28)=0.019, p = 0.98$) and left ($t(28)=0.58, p = 0.56$) thresholds, right ($t(28)=0.39, p = 0.70$) and left ($t(28)=.46, p = 0.64$) p1 latencies, right ($t(28)=1.76, p = 0.08$) and left ($t(28)=0.006, p = 0.99$) n1 latencies; right ($t(28)=2.45, p = 0.02$) and left ($t(28)=1.6, p = .13$) amplitude and interaural amplitude asymmetry ratio ($t(28)=0.727, p = 0.47$). Using a significance level at $p < 0.01$, results indicated no significant differences

between gender groups for all cVEMP response indices. An dependent sample t-test was also performed between the right and left ear for threshold ($t(29)=0, p=1$), p1 latency ($t(29)=0.8, p=0.93$), n1 latency ($t(29)=0.65, p=0.52$), and amplitude($t(29)=0.41, p=0.68$). No significant differences were found between ears.

A one-way between subjects ANOVA was conducted to examine the effect of three different fitness levels (superior/excellent, good/fair, poor/very poor) that were determined by VO₂max values on cVEMP response indices. Using a significance level at $p < 0.01$, results shows that fitness level does not significantly affect cVEMP right ($F(2, 25) = .72, p = .49$) and left ($F(2, 25) = .27, p = .76$) thresholds, right p1 ($F(2, 25) = .43, p = .65$) and n1 ($F(2, 25) = 1.7, p = .2$) values, left p1 ($F(2, 25) = 2.0, p = .15$) and n1 ($F(2, 25) = .53, p = .59$) values, right ($F(2, 25) = .17, p = .84$) and left ($F(2, 25) = 1.1, p = .34$) amplitude values. This suggests that fitness level determined by VO₂max values do not have a significant effect on cVEMP response indices.

A two-way between subjects ANOVA was also conducted to examine a potential interaction effect between gender and fitness level on cVEMP response indices. Using a significance level at $p < 0.01$, the interaction effect between gender and fitness level does not significantly effect cVEMP right ($F(2, 22) = .137, p = .27$) and left ($F(2, 22) = .16, p = .84$) thresholds, right p1 ($F(2, 22) = .479, p = .02$) and n1 ($F(2, 22) = .67, p = .51$) values, left p1 ($F(2, 22) = 5.3, p = .013$) and n1 ($F(2, 22) = 2.7, p = .08$) values, right ($F(2, 22) = .56, p = .57$) and left ($F(2, 22) = .16, p = .85$) amplitude values. This suggests that gender and fitness level determined by VO₂max values do not have a significant effect on cVEMP response indices.

Table 5.

Comparison of Mean (1 SD) Response Indices of cVEMP Between Gender Groups

	Ear	Male	Female	Total	<i>t</i> value
Threshold (dB nHL)	Right	77.3 (5.6)	77.4 (6.8)	77.3 (6.3)	0.98
	Left	76.5 (6.5)	77.9 (6.3)	77.3 (6.4)	0.56
P1 Latency (ms)	Right	16.1 (1.7)	15.9 (1.3)	16.0 (1.4)	0.70
	Left	16.2 (2.0)	15.9 (1.3)	16.0 (1.6)	0.64
N1 latency (ms)	Right	22.8 (1.5)	23.9 (1.6)	23.4 (1.6)	0.08
	Left	23.2 (2.0)	23.2 (1.3)	23.2 (1.6)	0.99
Amplitude (μ V)	Right	249.7 (191.3)	162.4 (115.4)	200.2 (156.3)	0.13
	Left	285.2 (169.0)	152.4 (128.1)	210.0 (159.2)	0.02
Interaural Amplitude Asymmetry Ratio (%)		26.1 (17.4)	21.6 (16.6)	23.6 (16.8)	0.47

OVEMP Results

oVEMP was also recorded from the same 30 adult participants. Nine subjects were excluded because 5 subjects showed absence of an oVEMP response, and 4 subjects showed absence of VEMP response in one ear. OVEMP responses in 23 subjects were analyzed. The table includes the mean and one standard deviation for oVEMP response indices; the table also results obtained from the independent t-test used to examine the potential cVEMP response differences between gender groups. In general, threshold, and latency values between male and female appears to be similar to each other; however, for male participants, amplitude values on the left ear appear to be larger than amplitude values on the right ear.

The Kolmogorov-Smirnov test was performed and results indicated that variables were normally distributed and the Levene's test was performed and results indicated no violation of homogeneity of variance assumption between gender groups. An independent sample t-test was performed between male and female participants for right ($t(19)=0.23, p = 0.82$) and left ($t(23)=0.12, p = 0.90$) thresholds, right ($t(19)=1.58, p = 0.13$) and left ($t(23)=1.6, p = 0.83$) n1 latencies, right ($t(19)=1.76, p = 0.08$) and left ($t(23)=0.215, p = 0.83$) p1 latencies, right ($t(19)=.13, p = 0.90$) and left ($t(23)=1.47, p = .15$) amplitude, interaural amplitude asymmetry ratio ($t(19)=1.20, p = 0.25$), and interaural n1 latency difference ($t(19)=.90, p = .381$). Using an alpha level of 0.01, results indicate no significant differences between gender groups for all oVEMP response indices. A dependent sample t-test was also performed between the right and left ear for threshold ($t(20)=1.7, p=0.1$), n1 latency ($t(20)=0.64, p=0.52$), p1 latency ($t(20)=1.2, p=0.21$), and amplitude ($t(20)=0.99, p=0.33$). No significant differences were found between ears.

A one-way between subjects ANOVA was conducted to examine the effect of three

different fitness levels (superior/excellent, good/fair, poor/very poor) that was determined by VO₂max values on oVEMP response indices. Using a significance level at $p < 0.01$, results showed that fitness level did not significantly affect oVEMP right ($F(2, 16) = .31, p = .73$) and left ($F(2, 16) = .80, p = .46$) thresholds, right n1 ($F(2, 16) = .80, p = .46$) and p1 ($F(2, 16) = 1, p = .37$) values, left n1 ($F(2, 16) = 1.6, p = .21$) and p1 ($F(2, 16) = .76, p = .48$) values, right ($F(2, 16) = .71, p = .50$) and left ($F(2, 16) = .55, p = .58$) amplitude values. This suggests that fitness level determined by VO₂max values do not have a significant effect on oVEMP response indices.

A two-way between subjects ANOVA was also conducted to examine a potential interaction effect between gender and fitness level on oVEMP response indices. Using a significance level at $p < 0.01$, the interaction effect between gender and fitness level did not significantly effect oVEMP right ($F(2, 19) = 2.1, p = .16$) and left ($F(2, 19) = 1.1, p = .33$) thresholds, right n1 ($F(2, 19) = .24, p = .78$) and p1 ($F(2, 19) = .67, p = .51$) values, left n1 ($F(2, 19) = 2.28, p = .14$) and p1 ($F(2, 19) = 1.1, p = .35$) values, right ($F(2, 19) = 1.14, p = .34$) and left ($F(2, 19) = .09, p = .91$) amplitude values. This suggests that gender and fitness level determined by VO₂max values do not have a significant effect on oVEMP response indices.

Table 6.

Comparison of Mean (1 SD) Response Indices of oVEMP Between Gender Groups

	Ear	Male	Female	Total	<i>t</i> value
Threshold (dB nHL)	Right	91.67 (4.1)	92.0 (2.5)	91.9 (3.0)	.82
	Left	91.1 (4.9)	91.0 (2.7)	91.0 (3.5)	.91
N1 Latency (ms)	Right	10.1 (2.2)	11.3 (1.3)	11.0 (1.7)	.13
	Left	11.3 (2.4)	11.1 (0.94)	11.2 (1.6)	.83
P1 Latency (ms)	Right	14.5 (3.4)	16.04 (1.20)	15.6 (2.1)	.13
	Left	15.8 (2.8)	16.2 (1.12)	16.0 (1.8)	.63
Amplitude (μ V)	Right	13.5 (10.2)	13.1 (5.5)	13.2 (6.8)	.90
	Left	20.1 (17.5)	13.2 (4.7)	15.7 (11.4)	.15
Interaural Amplitude Asymmetry Ratio (%)		18.2 (14.71)	11.8 (9.53)	13.6 (11.25)	.38
Interaural n1 Latency Difference (ms)		1.09 (1.67)	0.66 (0.60)	.78 (1)	.25

CHAPTER 5

DISCUSSION

CVEMP

The response rate for cVEMP was 100% in the present study, which is consistent with the response rates reported in literature (Kerdsiri et al., 2010; Wu et al., 2007). There are existing studies, however, that did not report 100% cVEMP response rate. Studies that examined age effect reported reduced cVEMP response rate for adults over the age of 60 (Janky et al., 2009; Welgampola et al., 2001). Studies that were designed to examine various recording parameters also did not report 100% cVEMP response rate due to different recording protocols being used in regards to stimulus rate, stimulus frequency and EMG recording levels (Isaradisaikul et al., 2012). The cVEMP response is a robust response that is easy to obtain in otologically people under the age of 60 years old when appropriate protocols are followed.

The mean cVEMP thresholds obtained for both ears was 77 dB nHL (± 6 dB nHL). These findings are consistent with findings from other normative data studies that use similar cVEMP protocols in regards to the positioning of the head, electrode location, stimuli and number of stimuli (Isaradisaikul et al., 2012; Janky et al., 2009; Park et al., 2010)). These findings are also consistent with findings from other normative data studies with protocols that are slightly different. Kerdsiri et al. (2010) reported similar cVEMP thresholds despite using a lower number of stimuli 80-150 instead of 200, and using a recumbent and head raised position instead of a sitting and head turned position. Welgampola et al. (2001) also reported similar cVEMP thresholds while using the recumbent and head raised position and using the sternum as ground instead of the forehead. The consistency of cVEMP threshold across different studies that used

different recording protocols suggests that cVEMP threshold may not be sensitive to changes in head position, electrode placement, and number of stimuli used.

Mean p1 latency values for both ears were approximately 16 ms (± 3 ms), and mean n1 latency for both ears were approximately 23 ms (± 3 ms) for this study. These values are in good agreement with those reported in previous cVEMP normative data studies such as 15.99 (± 2.04 ms) and 23.08 (± 1.50 ms) (Isaradisaikul et al., 2012), 16.24 (± 2.24 ms) and 22.97 (± 2.62 ms) (Janky et al., 2009), and 16.6 (± 1.5 ms) and 25.2 (± 2.0 ms) (Wu et al., 2007). However, p1 and n1 latency values have been reported to be as low as 12.0 (± 1 ms) and 20.03 (± 1.7 ms) from Welgampola et al. (2001), and 10.75 (± 1.34 ms) and 19.92 (± 2.43 ms) from Ochi et al. (2001). Latency values were reported to not be affected by stimulus level or muscle tonic level (Akin et al., 2004), therefore, the differences between the latency values from this study and other studies may be attributed to the differences in the protocol used to obtain cVEMP such as using the sternum as ground (Welgampola et al., 2001) and having a low number of stimuli of 50 (Ochi et al., 2001).

Mean amplitude values for both ears were approximately 200 μV ($\pm 158 \mu\text{V}$), with the lower limit being as low as approximately 50 μV and the upper limit as high as approximately 500 μV . This high variability in cVEMP amplitude value is also reported in various normative data studies. Welgampola et al. (2001) reported cVEMP amplitude of 72.5 μV (± 46.8); Janky (2009) reported cVEMP amplitude as low as 27.65 μV ($\pm 11.13 \mu\text{V}$), while cVEMP amplitude has been reported to be as high as 198.53 μV ($\pm 101.11 \mu\text{V}$) according to normative data by Isaradisaikul et al. (2008). This high variability in cVEMP amplitude values can be attributed to the muscle tonic level differences between participants. Colebatch et al. (1992) have reported that cVEMP amplitude is positively correlated with muscle tonic level; the more contracted the

SCM, the higher the cVEMP amplitude will be. Due the dependency of cVEMP amplitude on muscle tonic level, the use of an electromyogram to monitor muscle tonic level at a 30-50 μV level have been suggested in literature in order to decrease the variability in cVEMP amplitude (Akin et al., 2004). Muscle tonic level was not monitored in this study due to our lack of a muscle-monitoring device, which may provide an explanation to the wide range of cVEMP amplitude recorded. However, Isaradisaikul et al. (2008) also reported similar wide range of cVEMP amplitude while using an electromyogram to monitor and maintain muscle level at 40 μV . In contrast, Janky et al. (2009) reported a smaller range of cVEMP amplitude while using a blood pressure cuff to monitor muscle tonic level. Due to this discrepancy in regards to amplitude variability, it is hypothesized that monitoring muscle tonic level may not lead to a more predictable range of cVEMP amplitude. Although there is no literature available comparing cVEMP responses obtained from different recording equipment, another possible factor that may be responsible for this variability is the sensitivity of the recording equipment used to collect the cVEMP response.

Mean interaural amplitude asymmetry ratio percentage was approximately 26% ($\pm 17\%$). High variability is also seen in interaural amplitude asymmetry ratio percentage in literature. Many researchers have reported the percentage to be less than 1% (Maes et al., 2009; Wu et al., 2007), while others have reported the upper limit of the percentage to be greater than 40% (Kelsch, 2006; Welgampola 2001, Isiradisaikul, 2008). The high variability with interaural amplitude asymmetry ratio percentage from this study is expected as it is derived from the amplitude values, which was reported as highly variable.

cVEMP values obtained from this study are consistent with those reported in existing literature. However, due to the high variability in the amplitude values that were recorded

because cVEMP amplitude is highly influenced by muscle contraction, a potential confounding factor in this study is the lack of EMG activity monitoring. Studies have shown statistically significant differences in monitoring EMG activity (Akin et al., 2004), while other studies have not found statistically significant differences between monitored and unmonitored EMG activity (McCaslin et al., 2013; Ochi et al., 2001). Other EMG monitoring techniques have also been explored in literature. EMG monitoring has been conducted with blood pressure cuffs (Vanspauwen et al, 2006), while Isaradisaiikul et al. (2008) have indicated that a maximal head rotation to the contralateral shoulder to ensure symmetry is also as effective as EMG monitoring. In general, there is little agreement in literature on the best standard of practice for when it comes to monitoring muscle tonic level when recording VEMP. Due to the wide range of cVEMP amplitude values obtained from this study and the difficulty of comparing these values to existing literature because of the inconsistency of muscle monitoring methods, amplitude values as well as interaural amplitude asymmetry ratio percentage from this study should be interpreted with caution until similar results can be replicated in additional studies using our recording protocols.

A significant cVEMP response difference between gender groups and ears was not observed in this study. This is consistent with numerous existing cVEMP normative data studies, as there is no significant difference in cVEMP response between male and females, nor right and left ears (Basta, Todt & Ernst, 2005; Colebatch, Halmagyi & Skuse, 1994; Ochi & Ohashi, 2003).

OVEMP

Response rate for oVEMP was 70% in the present study. This rate is lower than the response rates of 80-100% reported in the literature (Chihara et al, 2007; Wang et al, 2009; Welgampola et al, 2009; Park et al, 2010). Low response rate is commonly reported in oVEMP studies due to low gaze elevation. Gaze elevation has been shown to have a significant influence on oVEMP amplitude as it activates the muscles where oVEMP responses are measured. Govender et al. (2009) observed a 50% increase in oVEMP amplitude in five subjects when they were instructed to gaze maximally upward instead of 30 degrees upward. Other studies attributed participants with missing oVEMPs to insufficient gaze angle as well as low stimulus level. For our study, participants were asked to direct their gaze maximally upward when an oVEMP response was absent or amplitude response was low. Similar to Govender et al. (2009), we observed an increase in oVEMP amplitude as well as an increase in oVEMP response rate when this technique was employed. Due to our success in employing this technique, it is recommended that researchers in future studies instruct their participants to direct their gaze maximally upward when an oVEMP response is seemingly weak or absent prior to recording it as such.

The mean oVEMP thresholds obtained for both ears was 92 dB nHL (± 2.5 dB nHL). This is consistent with the thresholds reported in literature as they range from 83 dB nHL to 92.5 dBnHL (Park et al., 2010; Piker et al., 2011). The thresholds obtained from this study most closely matched with those reported in Piker et al. (2011). This agreement is expected, as the protocols used to collect data were very similar across both studies except for the electrode montage used.

Mean n1 latency values for both ears were approximately 11 ms (± 1.2 ms) and mean p1 latency values for both ears were approximately 16 ms (± 1.1 ms). These latency values are within the latency range of those reported in previous studies (Chihara et al., 2007; Park et al., 2010; Wang et al., 2009; Welgampola et al., 2009). Longer latency values have also been reported in literature (Piker et al., 2011), which have been associated with longer rise/fall time of the stimulus. Longer latency values tend to be seen from studies that used 2 ms rise/fall time (Piker et al., 2011) in comparison to shorter latency values that have 1 ms rise/fall times with 2 ms plateau (Chihara et al., 2007; Wang et al., 2009; Welgampola et al., 2009; Park et al., 2010). In our study, a 2 ms rise/fall time was used, and our n1 and p1 latency values are consistent with what Piker et al. (2011) described as longer latency values compared to those with a 1 ms rise/fall times with a 2 ms plateau.

Mean amplitude values for both ears were approximately 14 μV ($\pm 9 \mu\text{V}$). This is higher and more varied than the amplitude values reported in literature 6.5 μV ($\pm 2.9 \mu\text{V}$) (Wang et al., 2009), and 7 μV ($\pm 1 \mu\text{V}$) (Chihara et al., 2007). This difference may be due to the different gaze angles used. In this study, participants were asked to gaze maximally upward when no oVEMPs were obtained at the 30 degrees angle. In contrast, oVEMPs were obtained at the 30 degrees angle in other studies (Chihara et al., 2007; Wang et al., 2009). These studies also used a different electrode montage compared to this study. Instead of having the ground electrode at the forehead, two non-inverting electrodes immediately beneath the eyelids and an inverting electrode on the chin, these studies have the ground electrode on the sternum, two non-inverting electrodes 1 cm beneath the eye lids and two inverting electrodes immediately underneath the inverting electrodes (Wang et al., 2009; Chihara et al., 2007). The difference can also be hypothesized to be due differences in recording equipment. Although there is no literature

available comparing oVEMP responses obtained from different recording equipment, similar to cVEMP, it is possible that this variability is due to the sensitivity of recording equipment.

Chihara et al. (2007) reportedly used a Neuropack Sigma to collect oVEMP data, while Wang et al. (2009) used the Smart EP Intelligent Hearing System.

Mean interaural amplitude asymmetry ratio percentage was approximately 13% ($\pm 11\%$). This percentage is consistent with those reported in literature (Piker et al., 2009; Piker et al., 2011). Mean interaural n1 latency difference was approximately .78 ms (± 1 ms). This value is within the range of the values reported in literature (Piker et al., 2009; Piker et al., 2011).

Similar to cVEMP, a significant oVEMP response difference between gender groups and ears was not observed in this study. However, various studies have noted a significant difference between gender groups in n1-p1 amplitude (Sung, Cheng & Young, 2011; Xie et al., 2011). This significant difference was ascribed to muscle bulk differences between males and females, suggesting that amplitude ratio values may be a more accurate manner of interpreting oVEMP rather than amplitude values (Sung, Cheng & Young, 2011; Xie et al., 2011). The discrepancy between this study and the studies discussed above may be due to a skewed male to female ratio from this study compared to a more balanced sample size from these studies.

Results obtained from this study also showed that fitness level does not have a significant effect on cVEMP and oVEMP values. While there is no evidence in current literature to corroborate this finding, there is a potential explanation for this non-significance. The cVEMP and oVEMP responses originate from the utricle and saccule, respectively. The utricle and saccule are two small, albeit important, organs in a much bigger system that contributes to our overall sense of balance. Our sense of balance is derived from not only the vestibular system, but

also the visual and somatosensory system. In an even bigger picture, our sense of balance is only one of many factors that are physiologic requirements for being upright and moving (Smith, 2015). In conjunction with our sense of balance, we also need to have the strength to stand/walk, a sound cognitive function and mental state, the ability to produce correct movement and coordination in order to be in an upright stance and moving (Smith, 2015). The non-significant finding in fitness level's effect on cVEMP and oVEMP values should not be generalized to fitness level to our sense of balance overall. The limitation of this part of study is that the relationship between fitness level and balance is examined through VEMP responses, which are very small measurements of our balance system as a whole. Perhaps in future studies, the relationship between fitness level and balance can be more thoroughly examined through other tests in the vestibular battery, or tests that involve other systems that are involved in maintaining equilibrium such as visual and somatosensory.

A general limitation of this present study was the sample size. This study was comprised of 30 participants with more female participants than male participants. The participants were mainly Towson University students whose age ranged from 20-26 years old. Due to the homogenous nature of the sample size, the normative data generated from this study should only be referenced for this particular age range. Future research can improve on this study by testing a more heterogeneous sample of participants in terms of age.

Conclusion

In conclusion, the purpose of this study was to establish normative data for cVEMP and oVEMP at the Towson University Hearing and Balance. Normative values, including mean and the ranges of +/- 1 SD and +/- 2 SD, for use in clinic, were created and are provided in

Appendices A and B. Both cVEMP and oVEMP tests are non-invasive tests that are simple to administer. They can be valuable additions to the vestibular test battery as they can provide insight to the otolith organs and its pathways.

APPENDIX A

CVEMP	Ear	Total (SD)	(2 SD)
Threshold (dB nHL)	Right	77.3 (6.3)	(12.6)
	Left	77.3 (6.4)	(10.8)
P1 Latency (ms)	Right	16.0 (1.4)	(2.8)
	Left	16.0 (1.6)	(3.2)
N1 latency (ms)	Right	23.4 (1.6)	(3.2)
	Left	23.2 (1.6)	(3.2)
Amplitude (μ V)	Right	200.2 (156.3)	(312.6)
	Left	210.0 (159.2)	(318.4)
Interaural Amplitude Asymmetry Ratio (%)		23.6 (16.8)	(33.6)

APPENDIX B

OVEMP	Ear	Total (SD)	(2 SD)
Threshold (dB nHL)	Right	91.9 (3.0)	(6.0)
	Left	91.0 (3.5)	(7)
N1 Latency (ms)	Right	11.0 (1.7)	(3.4)
	Left	11.2 (1.6)	(3.2)
P1 Latency (ms)	Right	15.6 (2.1)	(4.2)
	Left	16.0 (1.8)	(3.6)
Amplitude (μ V)	Right	13.2 (6.8)	(13.6)
	Left	15.7 (11.4)	(22.8)
Interaural Amplitude Asymmetry Ratio (%)		13.6 (11.25)	(22.5)
Interaural n1 Latency Difference (ms)		.78 (1)	(2)

APPENDIX C

	Fitness Level Category	VO₂max	Percentile
Males	Superior/excellent	51.1 to 61.2	80 - 99%
	Good/fair	42.2 to 49.2	40 - 75%
	Poor/very poor	26.6 to 41.0	1 - 35%
Females	Superior/excellent	44.0 to 55.0	80 – 99%
	Good/fair	35.5 to 43.4	40 – 75%
	Poor/very poor	22.6 to 34.6	1 – 35%

APPENDIX D

QUEENS COLLEGE STEP TEST

Step testing is convenient for both indoor and outdoor settings and for use with either one person or multiple people. Step tests come in many types, and perhaps one of the most popular is the Queens College Step Test (3, 4). Like most step tests, this test uses the measurement of recovery heart rate to estimate the subject's level of fitness (recall that heart rate returns to resting values more quickly following submaximal exercise in fitter people than it does in those who are less fit). Many of the available step tests were developed to estimate the fitness necessary for firefighting and other physically demanding occupations, but they are no longer used for occupational screening because participants sometimes used drugs (e.g., beta-blockers) to lower their heart rate and thus inflate their apparent fitness (you would not have been able to get one of these jobs unless your estimated VO_2max was greater than $45 \text{ ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$ [8]). The test remains useful, however, especially for groups of individuals participating in an exercise program.

Step 1: Since the accuracy of the test relies on the heart rate response, try to eliminate factors that might alter this outcome measure. Ideally, subjects will have avoided exercise for the previous 24 h, fasted for at least 2 h, and avoided the use of foods and drugs that alter heart rate (e.g., coffee, soda, energy drinks, diet pills, beta-blockers).

Step 2: Pair up with another student and find an appropriate space in which to conduct the test. Either you or your partner will start as the tester, and the other person will serve as the subject. You will then reverse these roles.

Step 3: Have the subject sit on the bench step and rest for 3 min, after which the tester should palpate the radial pulse for 15 s and record the resting HR.

Step 4: Set the metronome at $88 \text{ beats} \cdot \text{min}^{-1}$ to allow the subject to make contact with a foot on each beep in an up-up-down-down manner. This cadence results in the necessary $22 \text{ steps} \cdot \text{min}^{-1}$ necessary for the test on women. For men, set the metronome at $96 \text{ beats} \cdot \text{min}^{-1}$ and thus $24 \text{ steps} \cdot \text{min}^{-1}$.

Step 5: When the subject is ready, begin the 3 min test and start the stopwatch (see figure 7.3a).

Step 6: To avoid muscle fatigue, the subject should switch the leading leg at least once during the test.

Step 7: After exactly 3 min of stepping, the subject should stop. The tester should palpate for the radial pulse (see figure 7.3b). Begin counting at exactly 3:05 and count for 15 s (i.e., to 3:20).

Step 8: Calculate the predicted VO_2max by using the recovery HR in the equations below, where HR is $\text{beats} \cdot \text{min}^{-1}$.

Men: $\text{VO}_2\text{max} (\text{ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}) = 111.33 - (0.42 \times \text{HR})$

Women: $\text{VO}_2\text{max} (\text{ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}) = 65.81 - (0.1847 \times \text{HR})$

Step 9: Record your own data on the individual data sheet and on the group data sheet". (Haff & Dumke, 2012)

APPENDIX E

INFORMED CONSENT FORM

The Towson University Audiology Department is carrying out research to establish normative data for two vestibular tests known as the Sinusoidal Harmonic Acceleration and Vestibular Evoked Myogenic Potentials for the Towson University Hearing and Center (TU-HBC). Your role in this project will consist of attending a three-hour experimental session. Eventually, these data will be used as normative data for vestibular testing at the TU-HBC.

At these experimental sessions, you will be asked to be a subject of two vestibular tests. For the Sinusoidal Harmonic Acceleration test, you will be positioned and secured in a rotary chair in a darkened booth. The chair will then rotate in various positions and you will be tasked in various ways. The risk for this testing is possible nausea due to the rotation of the chair. For the vestibular myogenic evoked potential testing, you will be asked to contract your neck and eye muscle in various ways as you listen to clicking sounds. There is no risk for this testing. You will also be required to complete the Queens Step Test as a fitness measure. This involves stepping on and off of a platform for three minutes.

Participation in this study is voluntary. All information will remain strictly confidential. Although the descriptions and findings may be published, at no time will your name be used. You are at liberty to withdraw your consent to the experiment and discontinue participation at any time without prejudice. If you have any questions after today, please feel free to call 704-1234 and ask for Dr. Smith, or contact Dr. Debi Gartland, Chairperson of the Institutional Review Board for the Protection of Human Participants at Towson University at (410) 704-2236.

I, _____, affirm that I have read and understood the above statement and have had all of my questions answered.

Date: _____

Signature: _____

Witness: _____

THIS PROJECT HAS BEEN REVIEWED BY THE INSTITUTIONAL REVIEW BOARD FOR THE PROTECTION OF HUMAN PARTICIPANTS AT TOWSON UNIVERSITY.

****If investigator is not the person who will witness participant's signature, then the person administering the informed consent should write his/her name and title on the "witness" line.**

APPENDIX F

Questionnaire for vestibular testing (circle one)

- | | | |
|--|---|---|
| 1. Do you have any known/documented hearing loss? | Y | N |
| 2. Do you have any history of concurrent ear infections? | Y | N |
| 3. Do you have any history of active middle ear pathologies? | Y | N |
| 4. Have you ever experienced severe dizziness? | Y | N |
| 5. Have you ever experienced true vertigo? | Y | N |
| 6. Any unspecified balance problems? If so, please name? | Y | N |
| 7. Have you taken any anti-vertigo medications in the past 48 hours? | Y | N |
| 8. Have you taken any central nervous system suppressing medications or sedatives
in the past 48 hours? | Y | N |
| 9. Have you had any alcohol to drink in the past 48 hours? | Y | N |

APPENDIX G

Vestibular Testing Instructions

The following is a list of medications that should NOT be taken 48 hours before testing:

Alcohol	Any alcoholic beverages
Anti-Vertigo	Anitvert, meclizine, scopolamine, etc.
Antihistamines/decongestants	Benadryl, allegra, Claritin, etc.
Anti-Nausea	Dramine, bonine, Compazine, etc.
Tranquilizers	Valium, xanax, Ativan, serafem, etc.
Sedatives	Nembutal, Seconal, Placidyl, other sleeping pills

4 hours before testing:

- Don't smoke, ingest caffeine, or use nicotine
- Do not eat or drink, unless a small snack if you need to; water is fine
- Please limit or avoid make up or facial products, especially around the eyes
- Please wear pants and comfortable shoes (tennis shoes) for the fitness test

APPENDIX H



APPROVAL NUMBER: 14-A096

To: Tessa Durney
8000 York Road
Towson MD 21252

From: Institutional Review Board for the Protection of Human
Subjects Stacy Spaulding, Member

Date: Thursday, June 26, 2014

RE: Application for Approval of Research Involving the Use of
Human Participants



Office of Sponsored Programs
& Research

Towson University
8000 York Road
Towson, MD 21252-0001

t. 410 704-2236
f. 410 704-4494
www.towson.edu/ospr

Thank you for submitting an Application for Approval of Research Involving the Use of Human Participants to the Institutional Review Board for the Protection of Human Participants (IRB) at Towson University. The IRB hereby approves your proposal titled:

Normative data of the sinusoidal harmonic acceleration and vestibular evoked myogenic potentials for the towson university hearing and center (TU-HBC)

If you should encounter any new risks, reactions, or injuries while conducting your research, please notify the IRB. Should your research extend beyond one year in duration, or should there be substantive changes in your research protocol, you will need to submit another application for approval at that time.

We wish you every success in your research project. If you have any questions, please call me at (410) 704-2236.

CC: D. Emmanuel
File

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