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Normative Data for the Sinusoidal Harmonic Acceleration and Visual Suppression Subtests of Rotational Testing for the Towson University Hearing and Balance Center

By: Tessa Durney

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THESIS APPROVAL PAGE

This is to certify that the thesis prepared by ___**Tessa Durney**_entitled_ **Normative Data for the Sinusoidal Harmonic Acceleration and Visual Suppression Subtests of Rotational Testing at the Towson University Hearing and Balance Center**___has been approved by the thesis committee as satisfactorily completing the thesis requirements for the degree __**Doctorate of Audiology.**

Diana C. Emanuel, Ph.D. — 4/24/15

Chairperson, Thesis Committee Signature — Date

Elise Smith, Au.D. — 4/24/15

Committee Member Signature — Date

Tricia Ashby, Au.D. — 4.24.15

Committee Member Signature — Date

Janet V DeLany — May 9, 2015

Dean of Graduate Studies — Date

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ABSTRACT

NORMATIVE DATA FOR THE SINUSOIDAL HARMONIC ACCELERATION AND VISUAL SUPPRESSION SUBTESTS OF ROTATIONAL TESTING FOR THE TOWSON UNIVERSITY HEARING AND BALANCE CENTER

Tessa Durney

Vestibular function, specifically the vestibulo-ocular reflex (VOR), was evaluated in 31 adults ranging in age from 20-26 years old (18 females, 13 males) using the sinusoidal harmonic acceleration and visual suppression subtests of the rotary chair. All participants presented with normal hearing thresholds and no known vestibular issues. Twenty-nine adults completed a fitness test to determine overall cardiorespiratory fitness. These data were then used to examine fitness level in comparison to the VOR results. Normative data were collected for the new rotary chair in the Towson University Hearing and Balance Center. Test parameters included gain, phase, and symmetry of compensatory eye movements at various frequencies (speeds) of the rotary chair for both subtests. Gender and fitness level effects of these parameters were analyzed. No gender or fitness level effects were observed. The collected normative data are summarized in an appendix that can be used for diagnostic purposes. These data provide a useful baseline for audiologists to use to differentiate normal and abnormal vestibular function in individuals in this age range.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

KEY TO ABBREVIATIONS

ANOVA: Analysis of Variance
ANSI: American National Standards Institute
dB: Decibel
ENG: Electronystagmography
ER-3A: Etymotic Research 3A
GSI-61: Grason Stadler Instrument-61
HR: Heart Rate
Hz: Hertz
SCC: Semicircular Canal
SHA: Sinusoidal Harmonic Acceleration
TU-HBC: Towson University Hearing and Balance Center
VNG: Videonystagmography
VO_2MAX: Maximal Oxygen Consumption
VOR: Vestibular Ocular Reflex/ Vestibulo-ocular Reflex
VS: Visual Suppression

Chapter 1

Introduction

One key component of normal vestibular function in an individual is the functioning of the vestibulo-ocular reflex (VOR). The VOR determines how well the visual and vestibular systems work together to maintain a stable eye gaze when the head is in motion (Barin, 2009; Hirsch, 1986; Matta & Enticott, 2004; Slattery, Sinks & Goebel, 2011). Different pathologies of the peripheral and central vestibular systems can affect responses of the VOR. Vestibular testing, including assessment of the VOR, has developed over the years to help audiologists assess vestibular dysfunction in individuals with balance and dizziness complaints.

In order for audiologists to diagnose vestibular dysfunction, audiologists must record and analyze the VOR response. When recording the response, different parameters— gain, phase and symmetry—are analyzed to determine any dysfunction of the vestibular system. Two primary approaches to recording VOR responses have developed within current practice—the bi-thermal caloric test and whole body rotational testing. Caloric testing uses changes in temperature (warm and cold air, or water, into the ear) to elicit the VOR. Rotational chair testing elicits the VOR by rotations of the body and the head (Ahmed, Goebel & Sinks, 2009). In today's research and clinical applications, a computerized rotational chair is commonly used to record the VOR in individuals while the head is in motion involving sinusoidal rotations around a vertical axis.

Every rotational chair yields slightly different results depending on the environment it is in and its design. Therefore, when a new rotational chair is introduced

to a vestibular clinic, normative data need to be collected (Maes et al., 2008). The resulting normative data allow audiologists to analyze the different VOR parameters and differentiate between normal and abnormal responses.

The purpose of this present study is to collect normative data for the sinusoidal harmonic acceleration (SHA) subtest and visual suppression (VS) subtest of the Neurokinetics rotational chair in the Towson University Hearing and Balance Center (TU-HBC), for assessing vestibular function and specifically, the VOR.

Chapter 2

Literature Review

The vestibular system, the visual system, and the somatosensory system work with the central nervous system to establish equilibrium in the human body (Bear, Connors & Paradiso, 2007). The vestibular system is divided into the peripheral and central vestibular systems. The peripheral vestibular system detects and subsequently transmits information about head movement to the central vestibular system via neurons in the vestibular-cochlear nerve. The central vestibular system integrates this information with information from the visual and somatosensory systems to generate appropriate motor responses needed to maintain equilibrium (Bear et al., 2007). The peripheral vestibular system includes the otolith organs, the utricle, and saccule, which detect linear acceleration, and the semicircular canals (posterior, superior, and horizontal), which detect angular acceleration of the body and or head. The semicircular canals detect angular acceleration in the pitch (up and down or nodding "yes"), roll (making an arc from left to right, sometimes referred to as tumbling) or yaw (lateral left and right movement or shaking head "no") planes. The horizontal semicircular canal is specifically involved in the vestibulo-ocular reflex (VOR) as it detects side-to-side angular head movement (Bear et al., 2007) in the yaw plane. Specifically, the stimulus for the VOR is angular acceleration or change in velocity.

The vestibular and visual systems in particular work together to maintain focus of images on the fovea of the retina and a steady eye gaze when the head is in motion (Barin, 2009; Matta & Enticott, 2004; Hirsch, 1986; Slattery et al., 2011). The stimulus, or input, for the VOR is angular head movement with a change in velocity in the roll,

pitch, or yaw plane. The output response of the VOR is compensatory eye movement, equal to and opposite the direction of head movement. For example if the head moves thirty degrees to the right, the eyes will move thirty degrees to the left.

What is the VOR?

The VOR is the vestibular system's way of stabilizing the visual system as the eyes fixate on a stationary target (Barin, 2009; Mohammad et al., 2011). In order to achieve image stabilization, the vestibular system sends information to the visual system to produce an eye movement in the direction opposite of the head movement, but equal in velocity. (Corvera, Corvera-Behar, Lapilover & Ysunza, 2000; Mohammad et al., 2011). If the head turns to the left in a patient with a normal VOR, then the sensory cells in the left horizontal semicircular canal (SSC) are activated. These sensory cells stimulate the vestibular branch of the 8th cranial nerve and send information to the vestibular nucleus. This information is then sent to the contralateral 6th cranial nerve, the abducens nucleus, which excites the motor axons of the lateral rectus muscle of the right eye. Information from the 6th nerve is also sent back to the left side to excite the left 3rd cranial nerve, the oculomotor nerve, to excite the medial rectus muscle of the left eye. This causes both eyes to turn toward the right, a response opposite in direction to the leftward head movement. To ensure these eye movements happen quickly, another pathway from the vestibular nucleus excites the ipsilateral oculomotor nucleus and excites the left medial rectus muscle. Inhibitory information from the vestibular nucleus is also sent to the left lateral rectus muscle and the right medial rectus muscle to facilitate leftward eye movements. These excitatory and inhibitory responses allow an individual to maintain a

steady gaze while the head is in motion. Figure 1 shows the excitatory and inhibitory pathways of the VOR (Bear et al., 2007).

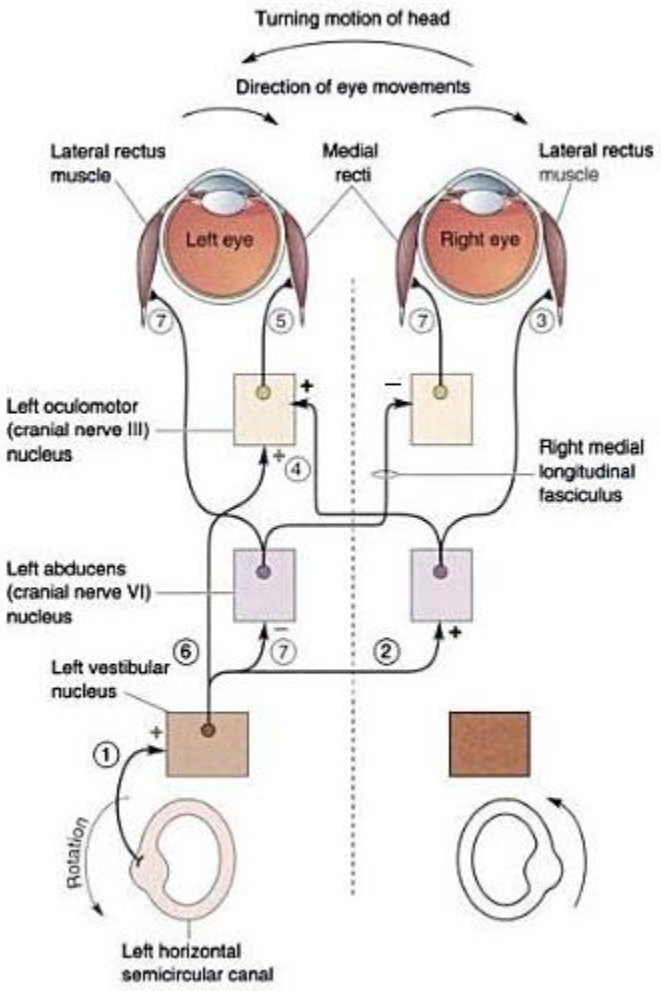


Figure 1. The vestibular-ocular reflex of the vestibular and visual system during a left head movement (Modified from Bear, Connors & Paradiso, 2007) (used with permission of Lippincott Williams and Wilkins. Appendix A).

Pathologies of the VOR

Central or peripheral vestibular pathologies can exert a negative effect (or influence) on the VOR. Peripheral vestibular lesions of the horizontal semicircular canals

or the sensory cells that communicate with the vestibular nerve (8th nerve) can cause abnormalities of the VOR by interfering with the excitatory and inhibitory responses of the system. Common peripheral pathologies triggering abnormal VOR responses include acute labyrinithitis, vestibular neuritis, vestibular ototoxicity, and canal paresis (Ahmed et al., 2009; Jutila, Aalto & Hirvonen, 2012; Parker, 1993; Sugita-Kitajima & Koizuka, 2014).

Central pathologies of the vestibular system and the visual system can also disrupt the VOR pathway. Specific lesions of the vestibular pathway in the central system that cause vestibular dysfunction include lesions of the central connections of the horizontal semicircular canal to the 8th nerve, lesions of the vestibular nucleus, or other cerebellum lesions (Furman & Cass, 2003). Additionally, ocular pathologies of central origin can also negatively affect the VOR. Lesions of the ocular motor neurons or ocular cranial nerves (i.e. ocular motor apraxia) may disrupt the excitatory or inhibitory function of the extra ocular muscles, causing dysfunction of the VOR or a total absence of the response (Jacobson & Shepard, 2008). Furthermore, neurologic diseases producing abnormal eye movements can negatively affect the VOR because precise and intact eye movements are needed for accurate VOR interpretation (Fife et al., 2000). These pathologies are summarized in Table 1.

Tests to Assess VOR

The VOR can be assessed informally by several bedside screening measures such as the head-impulse test, the dynamic visual acuity test, and the tandem Romberg test with eyes opened and closed (Brandt & Strupp, 2005; Vereek, Wuyts, Truijen & Van de Heyning, 2008). During the head-impulse test, the patient is asked to fixate on a target

Table 1

Summary of VOR Pathologies

VOR pathologies			
Site	Problem	Effect/Symptom	Cause
Peripheral	Lesions of the horizontal SCC or sensory cells	Disruption of the excitatory or inhibitory function of the cells	Acute Labyrinithitis Vestibular neuritis Vestibular toxicity Canal paresis
Central	Lesions of the central connections of the horizontal SCC to the 8th nerve, lesions of the vestibular nucleus, or other cerebellum lesions	Disruption of the excitatory or inhibitory function of the vestibular pathway	Tumors Infarctions
Central	Lesions of the ocular motor neurons or ocular cranial nerves	Disruptions of the excitatory or inhibitory function of the extra ocular muscles	Ocular motor apraxia Supranuclear palsy
Central	Abnormal eye movements	Inaccurate eye responses	Neurologic diseases

Note. Pathologies and vestibular test results can vary. Therefore, not all pathologies listed will yield all of these specific vestibular results.

while the clinician rotates the patient's head horizontally. In a normal vestibular system with a functioning VOR, the patient should be able to fixate on the target while the head is in motion (Traccis et al., 2004). When the VOR is disturbed, the patient is unable to maintain focus and abnormal eye movements are observed. During the dynamic visual acuity test, the patient first reads the lowest line possible of a Snellen visual acuity chart while the head is stable. The patient then rotates his/her head horizontally while reading the chart. If there is a drop in acuity of more than one line when the head is in motion, it suggests an abnormal VOR (Brandt & Strupp, 2005; Traccis et al., 2004). The tandem Romberg test assesses a patient's posture in an upright position with eyes open and then with eyes closed. This test can be used to determine whether or not changes in body position or posture occur. If changes do occur when the eyes are closed, a dysfunction of the vestibular system is possible (Vereek et al., 2008).

While these informal tools are appropriate screening measures, they cannot be used solely to diagnose vestibular abnormalities due to the inability to formally record the VOR response. Several formal testing measures exist to evaluate VOR function. These formal diagnostic tools are used to quantify the extent of any vestibular injury, as well as to determine the site of the deficit (i.e., peripheral or central vestibular lesions) (Slattery et al., 2011). The VOR can be formally assessed in two ways: caloric testing or rotational chair testing. The strongest predictor for identifying vestibular injuries that potentially affect VOR function is to administer both caloric testing and rotational chair testing (Ahmed et al., 2009). These tests excite the horizontal semicircular canals in different ways in order to elicit the VOR and associated eye movements. At low frequencies or speeds of head movement, gaze stabilization is maintained by the visual system. When

the frequency increases, however, the vestibular system dominates, sending more sensory input to the brain than the visual system, and provides information to keep the eyes fixated, resulting in the VOR (Hirsch, 1986). Therefore, it is vital to have controlled frequencies to ensure the response is coming from the vestibular system rather than the visual system.

Caloric testing. Caloric testing uses bi-thermal (warm and cool) air or water to stimulate each horizontal semicircular canal separately. By inserting air or water via the ear canal, thermal energy is transferred through the middle ear, to the inner ear and the horizontal semicircular canal (Fife et al., 2000). This testing can distinguish the side of any vestibular lesion due to the stimulation of one ear at a time. Unilateral weakness measurements determine if one ear is stronger or more responsive than the other. The thermal energy transfer either heats or cools the endolymph within the membranous labyrinth of the horizontal semicircular canal. As temperature increases, endolymph becomes less dense and rises upward creating utriculopetal flow of endolymph within the membranous labyrinth. This in turn deflects the cupula toward the utricule causing an excitatory response. Conversely, as temperature decreases, the endolymph becomes denser and sinks, creating utriculofugal flow which in turn deflects the cupula away from the utricle. Utriculofugal flow causes an inhibitory response. Neural responses are generated, relative to baseline neural firing rates, in the absence of a head turn. The air or water stimulus acts as the input stimulus for the VOR, in place of a head turn, evoking the output response of compensatory eye movements. As the VOR is activated a sensation of motion is elicited. Caloric testing is conducted with vision denied, or eyes closed, at the beginning of the test, therefore visual cues do not override the sensation of

motion. Eyes are opened at the end of the test to evaluate the ability to fixate on a target. Caloric testing only stimulates the VOR at low frequencies, from .002 to .004 Hz (Ahmed et al., 2009; Chiu et al., 2010). Because caloric testing only evaluates VOR function at low frequencies, correlating to very slow head movements, it is essential to additionally analyze VOR function at faster velocities, which are most similar to everyday head movements.

Rotational chair testing. Rotational chair testing is another testing approach used to assess the vestibular function of the horizontal semicircular canals (Ahmed et al., 2009). The rotational chair works as a system using precise and computer-controlled movements combined with computer-aided readouts of eye movements to provide information that is used to assess both the peripheral and central vestibular systems, as well as overall VOR function (Matta & Enticott, 2004). As the whole body is rotated either clockwise or counterclockwise, endolymph within the horizontal semicircular canal moves in the opposite direction as the head, thus deflecting the cupula either toward or away from the utricle, which then generates excitatory neural responses in the direction of the head turn. The head turn is the stimulus for the VOR which evokes a motor output of compensatory eye movements and elicits the sensation of motion. Testing is conducted in the dark therefore visual cues cannot assist the brain's perception of motion. The rotational chair subtests include frequencies between .01 and 1.0 Hz, speeds faster than caloric testing (Ahmed et al., 2009; Chiu et al., 2010). The rotational chair has several subtests designed to specifically evaluate vestibular function, including the sinusoidal harmonic acceleration test, the visual suppression test, step velocity test and the

subjective visual vertical test. This study will focus on the sinusoidal harmonic acceleration and visual suppression subtests.

Sinusoidal Harmonic Acceleration

The primary measure used to evaluate the VOR in the rotational chair is sinusoidal harmonic acceleration (SHA) testing. There are two main recording parameters for SHA testing. The first is the peak velocity, which is the maximum speed at which the chair rotates (i.e. 50 or 60 degrees per second) (Hirsch, 1986; Matta & Enticott, 2004). The second is the frequency at which the chair rotates. These different frequencies can range from .01 to 1.75 Hz (Ahmed et al., 2009; Chiu et al., 2010). The frequency chosen represents how many rotations the chair takes to reach the peak velocity. At a frequency of 1 Hz, a cycle will be completed in 1 second. If the frequency is 0.05 Hz, it will take 20 seconds to complete one cycle (Hirsch, 1986). Different frequencies of the rotation affect the magnitude of VOR response. Lower frequencies produce the weakest response from the VOR and, as the frequency increases, the VOR increases, which results in stronger eye movements (Hirsch, 1986; Shepard, 2009). The frequency at which the chair moves correlates with the calculated head movements (Shepard, 2009).

Recording parameters. The eye movements evoked by the VOR, during a rotation, are called ocular nystagmus. Nystagmus includes an initial slow phase eye displacement in the opposite direction of the head rotation. For example if the head moves thirty degrees to the right, the eyes move thirty degrees to the left. The second, or fast phase of nystagmus is a quick resetting of the eyes toward the direction of head rotation. For example, after the eyes move slowly thirty degrees to the left they quickly

return to the right, thus a right beating nystagmus is generated following head turns toward the right. Nystagmus is classified as right beating or left beating and is named in reference to the direction of the fast phase.

Nystagmus, or the eye movements, are recorded and subsequently analyzed in terms of phase, gain and symmetry (Ahmed, et al., 2009; Barin, 2009; Hirsch, 1968; Mohammad et al., 2011; Parker, 2003; Shepard, 2009; Slattery et al., 2011). Phase is determined by the time relationship between the eye movements and the head movements (Parker, 1993). It is the measurement of the delay between the stimulus (the head movement) and the response (the eye movement) (Hirsch, 1986; Slattery et al., 2011). The eyes should arrive at a point in time equal to the oppositely directed head movement. The phase of the VOR response has the greatest significance in indicating dysfunction of the peripheral vestibular system and it has high test retest reliability (Barin, 2009). The gain of the response is the ratio of the amplitude, or the magnitude of peak displacement of eye movement (nystagmus), to peak head movement (Ahmed et al., 2009; Brandt & Strupp, 2005; Hirsch, 1986; Mohammad et al., 2011). This measurement characterizes (or quantifies) the overall responsiveness of the system and represents any reduction of the response (Barin 2009). Therefore, a gain of 1 Hz indicates eye movements that are equal to the controlled head movements, and a gain of 0 Hz indicates an absence of eye movements when the head moves (Matta & Enticott, 2004). Lastly, symmetry of the response is analyzed to compare rightward and leftward eye displacements of the VOR. Symmetry indicates the difference between eye displacement during rightward and leftward head rotations (Ahmed et al., 2009; Parker, 1993; Slattery et al., 2011). Asymmetry of the eye movements may indicate unilateral dysfunction (peripheral or

central) of the vestibular system (Barin, 2009; Hirsch, 1968; Shepard, 2009). For example, an individual with a vestibular impairment of the right horizontal SCC will exhibit a stronger left beat nystagmus during the acute phase of the dysfunction. When central compensation occurs, symmetry will return to within normal limits (Jacobson, Piker, Do, McCaslin & Hood, 2012).

Factors influencing the response. When analyzing gain, phase, and symmetry of the VOR, it is important to control for factors that can impact the response. Both recording factors and subject factors can be manipulated or controlled to obtain the best possible VOR. The two main recording factors that can affect the VOR are the stimulus and the environment in which the testing takes place. As mentioned above, the frequencies that are assessed during rotational chair testing range from .01 to 1.75 Hz. The VOR is weakest in gain and phase at low frequencies and, conversely, strongest at high frequencies (Barin, 2009; Fife et al., 2009). At higher frequencies, there is less of a phase lead and the eye displacement is inverted and identical to the head displacement in normal responses (Barin, 2009; Hirsch, 1986). Also, in normal responses, the gain of the VOR response decreases with high frequencies rotations (Barin, 2009). However, even with these changes in the response, high frequency stimuli are more likely to identify more pronounced long-term deficits of the VOR (Sadeghi, Minov & Cullen, 2006). Another major recording parameter that affects the response of the VOR is the lighting in the room during the rotational testing. Visual fixation occurs when an individual stares at a target with eyes open in the light. This fixation, or ability to suppress any evoked nystagmus, occurs in any individual with a normal functioning vestibular system. When recording the VOR during SHA, the intended response is the nystagmus, therefore, a dark

room should be used for testing to minimize visual stimuli and to control for visual fixation so that nystagmus cannot be suppressed (Fife et al., 2000; Slattery et al., 2011). In a dark room, eye movements are reflective of the VOR and not visual stimuli (Goebel et al., 1995).

Recording parameters are not the only factors that result in variability in VOR test results; subject factors can also affect the VOR. Two physical characteristics, the gender and age of an individual, can impact the response. Some research has suggested that gender plays a role in vestibular issues. Vereek, Wuyts, Truijen and Van de Heyning (2008) noted that women tend to fall more often and become more off-balanced compared to men. However, the effect of gender on the VOR is still a controversial topic and warrants extensive research (Vereeck, Wuyts, Truijen & Van de Heyning, 2008). The age of an individual can also impact the VOR. Deterioration of the peripheral and central vestibular systems occurs later in life, especially after seventy years of age and as early as fifty years of age (Matheson, Darlington & Smith, 1999). Research has shown that vestibular sensory cells in the inner ear start to deteriorate by forty percent over the age of seventy (Matheson et al., 1999). Additionally, there is three percent neuronal loss of the vestibular nucleus per decade after forty, and the fibers of the vestibular nerve start to degenerate at this age (Matheson et al., 1999). Due to this deterioration of the system, signals exciting the vestibular system can become degraded, which leads to a weak or absent VOR. It is essential to consider an individual's age when assessing vestibular function during rotational testing to determine if abnormalities of the VOR are related to age or a true vestibular pathology.

Two other subject factors that should be examined during VOR testing are drug intake and attention. Blau, Schwade and Roland (2005) conducted a study with rotational testing on patients using diazepam, a drug used to suppress symptoms caused by vestibular dysfunction. Diazepam causes a decrease in arousal and alertness of an individual and reduces the resting discharge rate of the vestibular nuclei. When comparing the VOR response of subjects taking this drug to a control group, there was a reduction in the gain and phase changes (Blau, Schwade & Roland, 2005). This drug is one of many that can suppress the vestibular system. Therefore, when testing an individual during rotational testing, it is critical that the individual has not taken any suppressive drugs, decreasing the chance of any drug effects on the VOR.

Inattentiveness, or lack of alertness, can also negatively affect the response of the VOR. Matta and Enticott (2004) conducted a study to determine the effect mental alerting tasks (i.e. arithmetic problems or naming exercises) had on the VOR response. They found that gain of the VOR was significantly lower at all frequencies in the non-alert condition. The gain increased through the frequency range when the subjects were given mental alerting tasks while the chair was in rotation (Matta & Enticott, 2004; Parker, 1993). It is important when conducting rotational testing to mentally task subjects during SHA to elicit the greatest VOR response.

Visual Suppression Subtest

The visual suppression (VS) test is another subtest of the rotary chair that assesses the VOR. In a normal vestibular system, an individual has the ability to fixate on a target when the head is in motion and can suppress the compensatory eye movements and VOR (Hain & Rudisill, 2008). This test involves the patient staring at a fixed target light while

the chair completes the sinusoidal harmonic acceleration. Similarly to the SHA, gain, phase, and symmetry are recorded. In individuals with a normal VOR, research has shown that the VOR gain can decrease by 75-90% (Jacobson et al., 2012) and is referred to as gain reduction. When a patient has a peripheral vestibular impairment, the ability to suppress the VOR can restore symmetry of the vestibular system and relieve vertigo symptoms (Hain & Rudisill, 2008; Jacobson et al., 2012). The inability to suppress the VOR response could indicate central vestibular pathologies. Therefore, it is essential for differential diagnosis to evaluate the ability to fixate on a target during the visual suppression subtest.

Abnormalities of the VOR

Vestibular testing, including rotational chair testing, is conducted to assess the function of the vestibular system, identify the presence of pathology, quantify the extent of the effect, and localize the deficit (Slattery, et al., 2011). A normal vestibular system and properly functioning VOR should have a gain of 1 and a phase shift of 180 degrees (Fife et al., 2000). A normal vestibular system should also have symmetrical right and left beating nystagmus (Parker, 1993). Acute lesions of the horizontal semicircular canal can result in an asymmetry of the nystagmus to the opposite side of the lesion and a decrease in gain along with an increase in phase lead (especially in the lower frequencies (Parker, 1993; Sadeghi et al., 2006). Asymmetries often indicate incomplete central compensation processes or an uncompensated vestibular pathology and may correspond with an underlying spontaneous nystagmus or positional nystagmus during videonystagmography (VNG) or electronystagmography (ENG) testing. Symmetry values may return to within normal limits following central vestibular compensation. A

decrease in gain is seen in both unilateral and bilateral vestibular dysfunction. Also phase changes and a VOR asymmetry greater than twenty percent implies dysfunction (Slattery et al., 2011). Individuals with bilateral vestibular loss show a decrease in gain at all frequencies with the amount of decrease depending on the amount of damage. Lesions of the central VOR pathways can produce abnormalities, for example, the gain of the nystagmus can be increased or the inability to suppress the VOR during visual fixation/suppression (Jacobson et al., 2012; Parker, 1993). Table 2 summarizes the different VOR parameters as seen in vestibular pathologies.

Advantages and Limitations to Rotational Chair Testing

There are several advantages over caloric testing in using the rotational chair to assess VOR function. The use of the rotational chair, to perform SHA, results in an input that can be accurately controlled and modified by a computer to get objective data (Fife et al., 2000; Hirsch, 1986; Matta & Enticott, 2004; Parker, 1993). Because the stimulus is controlled and precise, the same parameters will elicit the response in the same exact way across different test sessions. Another advantage is that the chair is the only vestibular tool that can quantify the impact a lesion has on the vestibular system (Shepard, 2009). Furthermore, unlike caloric testing, the stimulus for SHA in the rotational chair is unrelated to the physical characteristics of the outer and middle ear and the temporal bone area (Ahmed et al., 2009). It is also more comfortable for the patient than caloric testing and it does not lead to vertigo, which can be induced by caloric testing (Hirsch, 1986). Therefore, when possible and available, most audiologists find the rotary chair to be the superior clinical tool in a vestibular protocol (Barin, 2009; Fife et al., 2000).

Table 2

Summary of the VOR parameters seen for different vestibular pathologies

Type	Gain	Phase	Symmetry	Visual Suppression
Normal	1	180º	Symmetrical	Decrease of VOR by 75-90%
Acute lesions of the horizontal semicircular canal	Decrease (esp. lower frequencies)	Increased phase lead	➢ 20%	Decrease of VOR by 75-90%
Bilateral	Decrease (all frequencies)	*Increased phase lead	➢ *20%	Decrease of VOR by 75-90%
Lesions of central VOR pathways	Increase	Possible reduced phase lead	➢ 20%	Gain reduction less 75-90%

**Note. P*hase and symmetry often cannot be interpreted when gain is decreased (0 or less) across frequencies. If a VOR is not being elicited then there is no compensatory eye movement and phase and symmetry values are not accurate.

Although there are many advantages of using the rotational chair, compared with caloric testing, the rotational chair has some limitations. A rotational chair is a sophisticated piece of machinery that is very expensive to purchase, maintain and move, and is difficult to house due to its large size (Chiu et al., 2010; Fife et al., 2000). Therefore, it is not a standard piece of test equipment available for testing vestibular function in every clinic. The other main disadvantage involves the stimulus of the rotational chair. The stimulus is controlled and can potentially lead to unnatural movements of the head; an individual with normal VOR function might not produce a measured VOR exactly at the speeds of the rotational chair (Chiu et al., 2010). Also, because the head is fixed and the chair moves, both ears are stimulated, making it difficult to distinguish between unilateral and bilateral vestibular pathologies (Fife et al., 2000). Regardless of the limitations of the rotational chair, its use in conjunction with caloric testing is the strongest predictor of peripheral vestibular pathologies (Ahmed et al., 2009; Barin 2009; Fife et al., 2000; Parker, 1993).

Rehabilitation of the Vestibular System

Understanding the advantages and limitations of the rotational chair can help audiologists acknowledge the importance of using rotational testing and the SHA and VS subtests. Early diagnosis of vestibular dysfunction can have a major impact on the management and outcome of individuals with documented pathologies by identifying the pathology and implementing rehabilitation as early as possible (Ahmed et al., 2009; Corvera et al., 2000). The rotational chair produces VOR responses that can help audiologists diagnose vestibular pathology, quantify vestibular dysfunction, and provide information necessary to develop appropriate rehabilitation plans for patients with

vestibular dysfunction. These rehabilitation plans should focus on utilizing any residual vestibular function and retraining the brain to rely more on visual and somatosensory input. By retraining the brain, rehabilitation helps the brain to access the somatosensory and visual symptoms more readily without reliance on the damaged vestibular system (Fife et al., 2000; Sugita-Kitajima & Koizuka, 2009). Individuals with vestibular pathologies respond well to 10 to 12 week rehabilitation programs to correct problems with dizziness and instability. These programs tend to have integrated eye, head, and body movement exercises to help the nervous system compensate for the impairment in the vestibular system and the VOR (Matheson et al., 1999).

Normative Data

Vestibular rehabilitation may be implemented when an individual is diagnosed with a vestibular pathology. Vestibular pathologies can be assessed through rotational chair testing using the SHA, visual suppression, step velocity, and subjective visual vertical subtests. An understanding of VOR and a normal response can help audiologists determine if a response is abnormal. To accurately assess a VOR response in an individual, normative data are needed (Fife et al., 2000; Maes et al., 2008). It is recommended that audiologists gather and calculate normative data on their own equipment with individuals having no known vestibular dysfunction when using any new laboratory equipment. These data can help determine the most valid and reproducible gain, phase, and symmetry results (Maes et al., 2008). Most commercial rotational chair systems need site-specific normative data for each product (Fife et al., 2000).

Statement of Purpose

The main goal of this study was to establish normative data using standard protocols and parameters of the SHA and VS subtests using the Neurokinetics rotational chair at the Towson University Hearing and Balance Center (TU-HBC). This research project was essential to the operation of the new vestibular clinic. Normative data will give Towson University audiologists reliable gain, phase, and symmetry parameters of the nystagmus that can be used to establish normal from abnormal VOR responses and to analyze any abnormal results (Maes et al., 2008). Research has suggested a controversy about how gender affects the functioning of the vestibular system. Therefore, a secondary goal of this study was to identify any gender related effects on the VOR during SHA and visual suppression testing. Finally, there is no documented research concerning how an individual's overall cardiorespiratory fitness level affects the vestibular system. A third goal of this study was to determine any fitness level related effects on the VOR.

Chapter 3

Methods and Materials

Participants

Thirty-one adults ranging in age from 20-26 years served as participants (18 females, 13 males). 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 B. Participants were recruited through fliers, Towson University students' emails, and verbal recruitment.

Researchers contacted the participants and asked several questions via email. A vestibular questionnaire was used to rule out any participants with self-reported middle ear pathologies, hearing loss, or vestibular dysfunction (Appendix C). A fitness questionnaire, the Par-Q, was administered to evaluate physical activity readiness (Appendix D). During this interview process, the participants were given pretest instructions, specifically, to not drink alcohol or take any suppressive medications 48 hours prior to testing (Appendix E).When the participants arrived at the TU-HBC, an audiological evaluation including tympanometry and pure-tone audiometry was completed. Due to the possibility that fitness levels can affect the VOR, The Queens Step test was completed to evaluate overall cardiorespiratory fitness level (Appendix F). This test involved participants stepping on and off of a heightened step for 3 minutes while the examiner evaluated the active heart rate at 3 minutes and 20 seconds with a pulse oximeter. This test yielded data used to calculate VO_2max values and categorical fitness levels. VOR function was assessed by the SHA and the VS subtest, using the rotational chair, as described below.

Equipment and Procedures

Tympanograms with normal static compliance (0.3-1.4 ml) and peak pressure (-150-+100 daPa) verified normal middle ear function using a GSI Tympstar immittance bridge. Pure tones for air conduction testing were measured via Etymotic Research (ER)-3A insert headphones. Pure tone thresholds, both air conduction and bone conduction, were established to be better than 20 HL at octave frequencies from 500 through 4000 Hz. These thresholds were obtained using the GSI-61 clinical audiometer in a sound treated booth. Participants were excluded from the study if they did not meet these criteria. Both the audiometer and immittance bridge were calibrated according to ANSI standards in August 2014. A computerized controlled rotational chair (I-Portal NOTC from NeuroKinetics) and an eye tracking system that records and measures eye movements (I-Portal VOG) were used to assess the VOR. This system was calibrated in November 2014. Both calibration dates were prior to the start of data collection for this study.

Rotational testing was performed using the SHA and VS subtests of the NeuroKinetics rotational chair and the NeuroKinetics VEST Version 7.0.1 software. The participant was positioned in the rotary chair in a darkened booth and secured with head restraints to keep the head stable. Calibration of the chair was performed before each trial for each participant using the procedures recommended by the manufacturer. The response was recorded using 4D video-oculography with a binocular eye tracking device, attached to the head. A computer analysis of the eyes in I-Portal V.3.0 reflected horizontal and vertical movements. The VOR gain, phase, and symmetry were measured at several frequencies of the SHA subtest, specifically, 0.01, 0.02, 0.04, 0.08, 0.16, 0.32,

1.28 and 1.75 Hz and for the VS subtest at .08 and .32 Hz. The peak velocity of 60 degrees per second was used for all frequencies. Mental altering tasks were given during each frequency of rotation (Appendix G) for the SHA subtests. Mental alerting tasks were not used for the VS subtest.

Statistical Analysis

Rotational chair data were collected and analyzed using the NeuroKinetics VEST Version 7.0.1 computer system. Gain, phase, and symmetry were recorded and analyzed with this software for each trial for all participants. Descriptive and inferential statistical analyses conducted using Excel and SPSS software.

Chapter 4

Results

Participants

Data from all 31 participants were used to assess the SHA and VS parameters. However, two of the 31 participants were excluded from the data analysis for fitness level due to the unavailability of the fitness equipment during testing. Data was analyzed from the remaining 29 participants (17 females, 12 males). Mean ages and VO_2max values for the participants are displayed in Table 3 below. The table includes the range and mean ages of males and females and the range and mean VO_2max values for males and females, including the population percentile the VO_2max value of each gender.

Rotational Chair Testing

Thirty-one participants completed both the SHA subtest and the VS subtest in the rotational chair. Gain, symmetry and phase values were all documented and analyzed. Table 4 shows the mean and standard deviation of each test parameter at different frequencies for the SHA and VS subtests. Examination of this table shows an increase in gain as the frequency increases, a decrease in phase as the frequency increases, and no noted pattern of symmetry during the SHA subtest. The VS subtest yielded low gain at all frequencies compared to SHA and no specific patterns of symmetry or phase. Gain reduction percentages represent the amount of suppression of the eye movements, at a specific frequency, during SHA and VS subtests. In Table 4, gain reduction percentages were similar for both frequencies.

Table 3

Mean age and VO_2max values for male and female participants.

	Age			VO_2max		
Participants	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	18	23.5 (1.62)	20-26	17	38.97 (4.02) (55^{th} %)	32.56-46.97
Total	31	23.39 (1.71)		29	44.27 (9.38)	

Note. VO_2max 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.

Table 4

Descriptive Statistics of the Sinusoidal Harmonic Acceleration (SHA) and Visual Suppression Subtests of the Rotary Chair at Various Frequencies for Four Parameters: Gain, Symmetry, Phase, and Gain Reduction (%).

		Gain	Symmetry	Phase
Frequency	N	M (*SD*)	M (*SD*)	M (*SD*)
		Sinusoidal Harmonic Acceleration		
.01 Hz	31	.38 (.10)	1.52 (11.24)	41.63 (6.67)
.02 Hz	31	.43 (.09)	3.30 (9.27)	23.67 (5.14)
.04 Hz	31	.51 (.13)	3.98 (8.46)	11.52 (4.05)
.08 Hz	31	.50 (.14)	-.36 (11.71)	2.42 (3.66)
.16 Hz	31	.53 (.14)	-1.41 (9.02)	1.57 (2.76)
.32 Hz	31	.57 (.12)	.31 (7.81)	1.53 (3.12)
1.28 Hz	31	.87 (.12)	-1.81 (5.40)	-0.34 (11.50)
1.75 Hz	31	.79 (.21)	.24 (10.79)	-15.11 (18.06)
		Visual Suppression		
Frequency	N	Gain	Symmetry	Phase	Gain Reduction %
.08 Hz	31	.06 (.04)	3.91 (22.05)	-0.63 (35.09)	86.53% (8.61)
.32 Hz	31	.08 (.05)	5.29 (14.29)	3.12 (14.11)	85.41% (10.62)

Statistical Analysis

All data were analyzed with mixed measures analysis of variance (ANOVA). All effects for SHA and VS subtests are reported with a significance level at $p < .05$. Due to the violation of the sphericity assumption in all data sets, the Greenhouse-Geisser correction was applied to all statistical analyses due to its conservative correction. The adjusted degrees of freedom (df) are indicated for each significance test.

Sinusoidal Harmonic Acceleration

The SHA parameters (gain, symmetry and phase) were analyzed with three 2 x 8 (gender by frequency) mixed ANOVAs with a VO_2max value covariate, to determine gender effects and fitness level on the values of the SHA at different frequencies. Three additional 3 x 8 (fitness level by frequency) mixed ANOVAs were conducted to determine any differences in SHA values using the three following categorical fitness levels that were determined by VO_2max values; 1) Superior/excellent, 2) Good/fair, 3) Poor/very poor. These categories are summarized in Appendix H.

Gain. Figure 2 shows the mean values of gain values at different frequencies for males and females. Examination of Figure 2 below indicates no specific trends between gain of males and females on any of the different frequency SHA subtests. A 2 x 8 (gender x frequency) mixed ANOVA with VO_2max as a covariate revealed no significant effects of gender, indicating gain values at all frequencies were generally the same for male and female participants, F (1, 26) = 3.087, p = .091. The covariate, VO_2max value, was non-significant, indicating that fitness level at a measurable VO_2max value does not affect the gain values at any frequency, F (1, 26) = .851, p = .365.

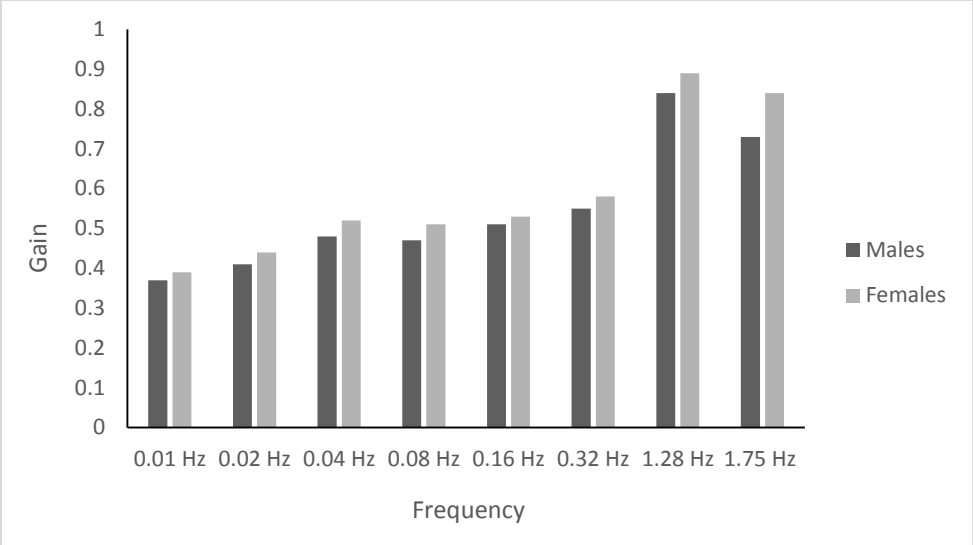


Figure 2. The mean gain values of male and female participants during the Sinusoidal Harmonic Acceleration subtest.

There was no significant interaction effect between frequency and gender, F (2.245, 58.381) = .255, p = .800 and no significant interaction effect between the frequency and VO_2max, F (2.245, 58.381) = .137, p = .893, indicating that VO_2max and gender do not affect the gain at different frequencies.

Figure 3 shows the relationship between different fitness levels on gain values at different frequencies during the SHA. Examination of Figure 3 shows no apparent difference between fitness levels. A 3 x 8 (fitness level x frequency) mixed ANOVA was conducted, and there was no significant effects of fitness level, indicating no differences in gain value at any frequency when fitness level varies from very poor to superior, F (2, 26) = .039, p = .962. There was a significant effect of frequency, indicating that gain values are significantly different at each frequency during the SHA subtest, F (2.238, 58.196) = 66.083, p = .000. There was not a significant interaction effect between frequency and fitness level, F (4.447, 58.196) = .629, p = .661.

Symmetry. Figure 4 shows the relationship between males and females on the symmetry values at different frequencies of the SHA. Examination of Figure 4 indicates no apparent differences between gender. A 2 x 8 (gender x frequency) mixed ANOVA with a covariate of VO_2max value was conducted to determine gender or fitness level differences in symmetry values. There was no significant effect of gender, indicating no differences in symmetry values at all frequencies between male and female participants, F (1, 26) = .017, p = .898, as seen in Figure 2 below. VO_2max values were non-significant, indicating that symmetry values were generally the same at all VO_2max values, F (1, 26) = .065, p = .801. There was no significant interaction effect between frequency and gender in symmetry values, F (3.507, 91.180) = .387, p = .793 and no

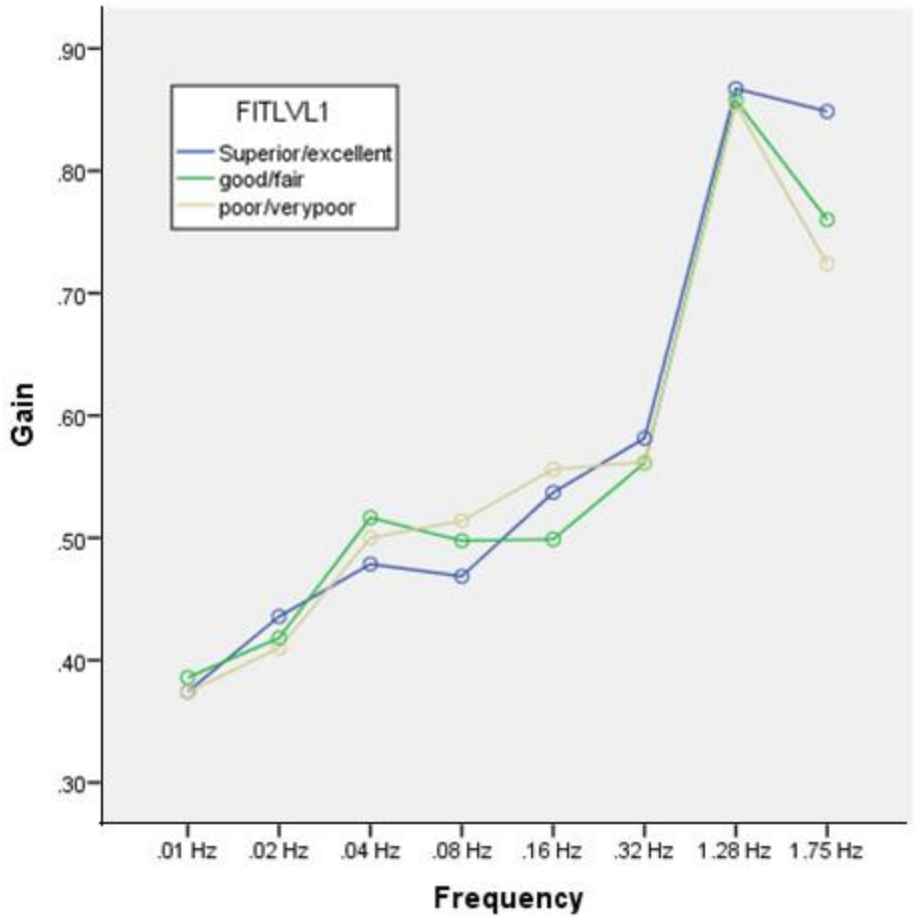


Figure 3. Mean gain values at various different fitness levels during the Sinusoidal Harmonic Acceleration subtest.

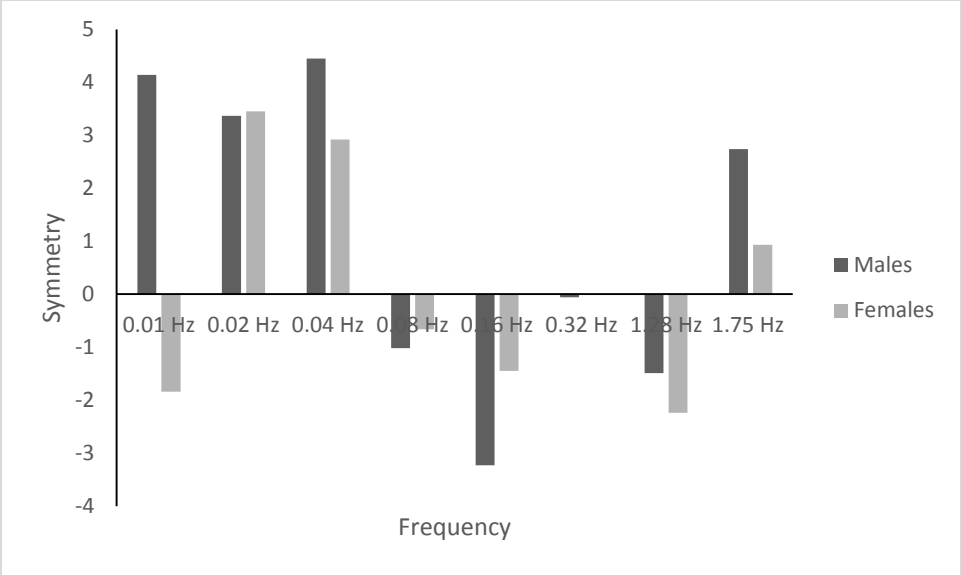


Figure 4. The mean symmetry values of male and female participants during the Sinusoidal Harmonic Acceleration subtest.

significant interaction effect between frequency and VO_2max, F (3.507, 91.180) = 1.296, p = .279, indicating that frequency differences are unaffected by VO_2max and gender.

Figure 5 shows the relationship between symmetry values at three different fitness levels at various frequencies. Examination of Figure 5 indicates no clear differences between fitness levels. A 3 x 8 mixed (fitness level x frequency) ANOVA administered found no significant effects of fitness level, F (2, 26) = .041, p = .959. This indicates that there is no different in symmetry values at any frequency when the fitness levels vary. There was a significant effect of frequency, indicating that symmetry values are significantly different at each frequency during the SHA subtest, F (3.563, 92.641) = 2.660, p = .043. There was not a significant interaction effect between frequency and fitness level, F (7.126, 92.641) = 1.570, p = .153.

Phase. Figure 6 represents the mean male and female phase values at various frequencies. Examination of this figure shows no apparent differences between male and female gain values. A 2 x 8 (gender x frequency) mixed ANOVA with a covariate of VO_2max value was conducted to determine gender and VO_2max differences in phase values. There was no significant effect of gender, indicating phase values at all frequencies are generally the same between males and females, F (1, 26) = 3.078, p = .091, as seen in Figure 3 below. Fitness level was non-significant, indicating that phase values were generally the same at all VO_2max values, F (1, 26) = 2.473, p = .128. There was no significant interaction effect between frequency and gender in the phase values, F (1.696, 44.085) = .699, p = .480. There was no significant interaction effect between frequency and VO_2max value, F (1.696, 44.085) = .816, p = .431, indicating that frequency differences are unaffected by VO_2max and gender.

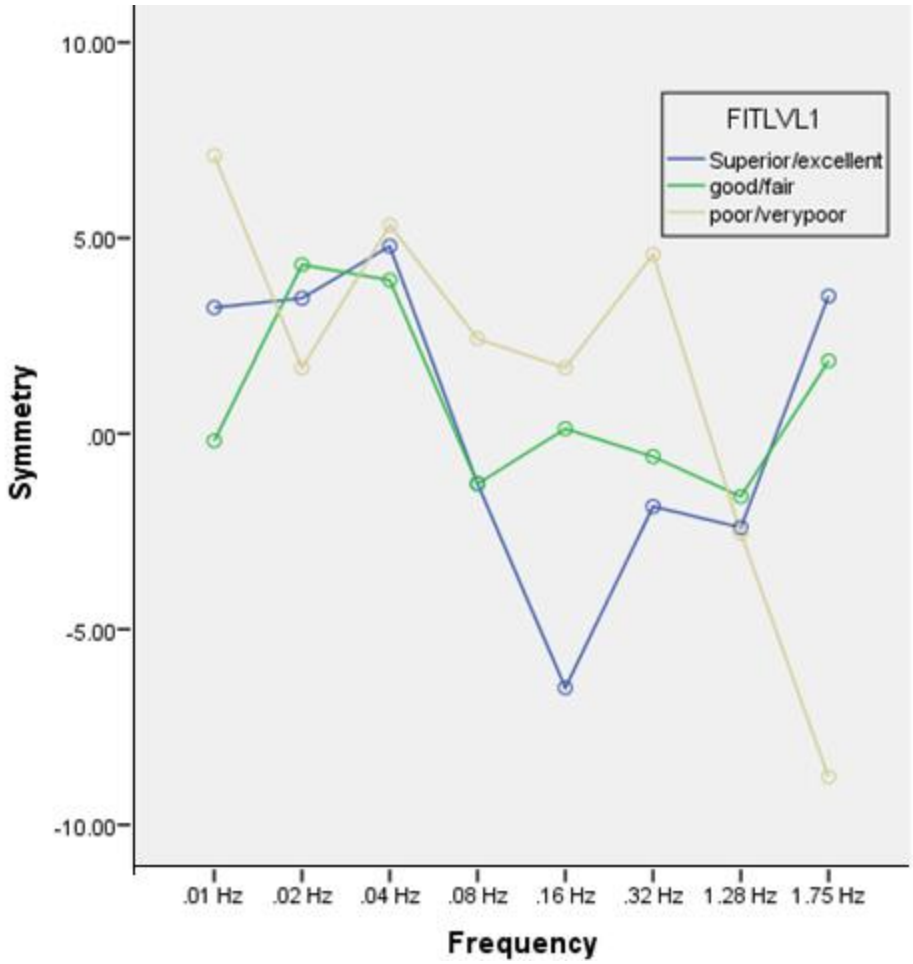


Figure 5. Mean symmetry values at various different fitness levels during the Sinusoidal Harmonic Acceleration subtest.

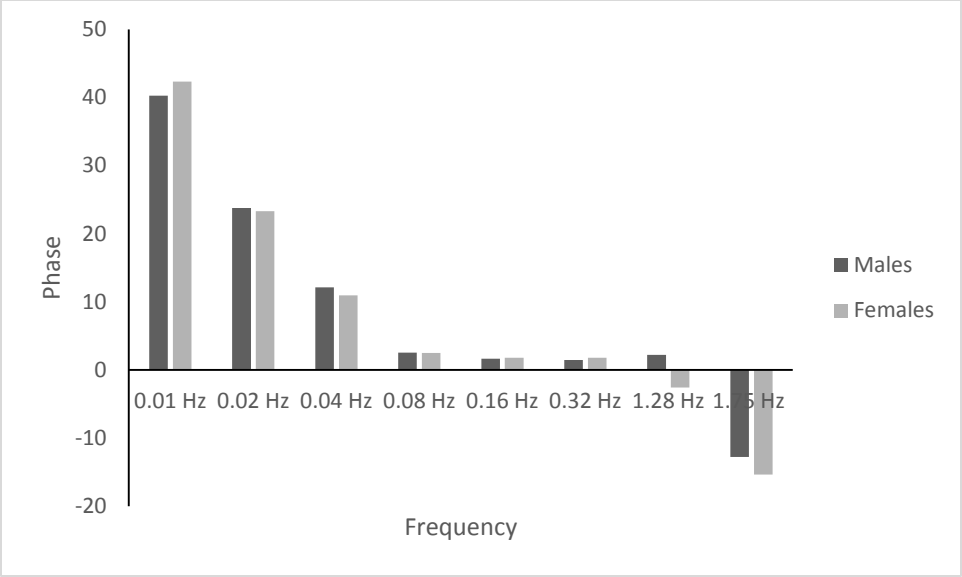


Figure 6. The mean phase values of male and female participants during the Sinusoidal Harmonic Acceleration subtest.

Figure 7 shows the relationship between phase values and fitness level at different frequencies. Examination of this figure shows no clear differences between fitness level and phase values. A 3 x 8 mixed (fitness level x frequency) ANOVA was conducted to analyze effects of categorical fitness level on phase values at different frequencies. There was no significant effects of fitness level, F (2, 26) = .255, p = .777, indicating that fitness level does not affect the phase values at any frequency. There was a significant effect of frequency, F (1.699, 44.169) = 99.411, p = .00. This indicates that phase values are significantly different at each frequency. There was not a significant interaction effect between frequency and fitness level, F (3.398, 44.169) = .379, p = .792.

Visual Suppression Subtest

The visual suppression parameters (gain, symmetry, phase, and gain reduction) were analyzed with four 2 x 2 (gender by frequency) mixed ANOVAs with a VO_2max value covariate and four 3 x 2 (fitness level by frequency) mixed ANOVAs. These were used to determine any differences of gender or fitness level on gain, symmetry and phase values and gain reduction percentages at different frequencies during the visual suppression subtest.

Gain. Figure 8 represents gender differences between gain values at two different frequencies during the VS subtest. Examination of this figure indicates no apparent differences of gender on gain values. A 2 x 2 (gender x frequency) mixed ANOVA with a covariate of VO_2max revealed no significant effects of gender, indicating gain values at both frequencies were generally the same for each gender, F (1, 26) = .973, p = .333. The VO_2max value was not significant, F (1, 26) = .015, p = .904. This indicates that fitness level using the VO_2max value does not affect gain values. There was no significant

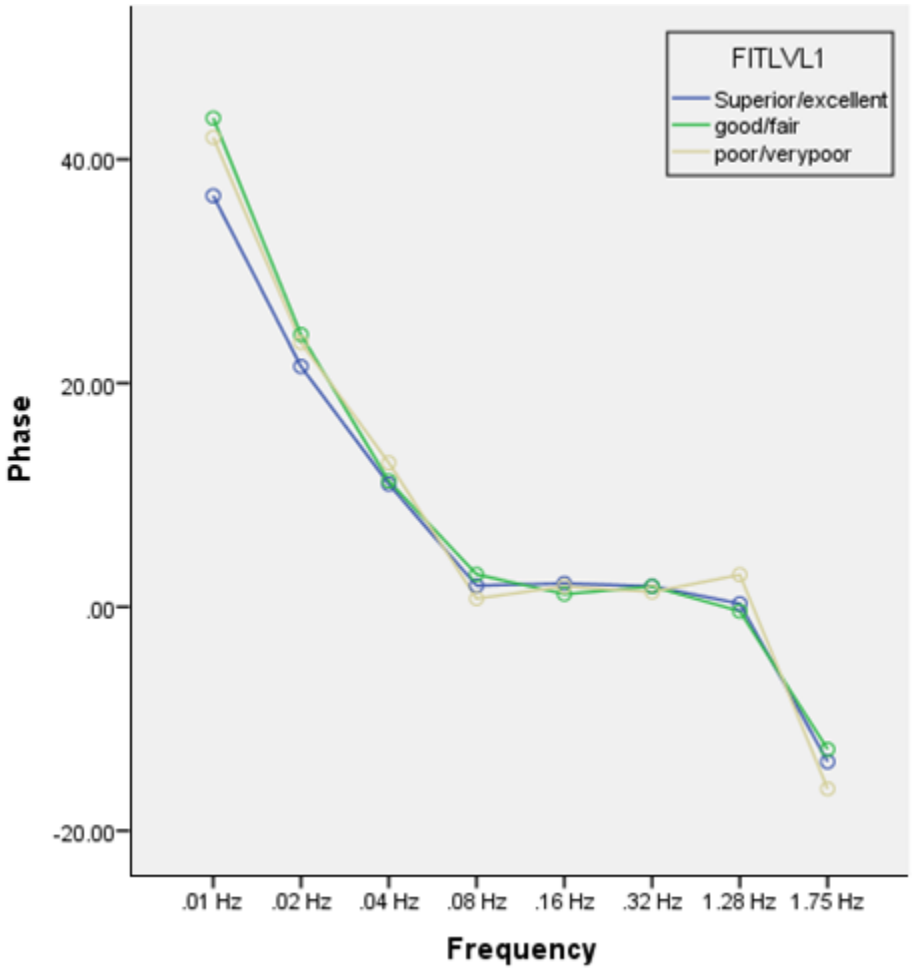


Figure 7. Mean phase values at various different fitness levels during the Sinusoidal Harmonic Acceleration subtest.

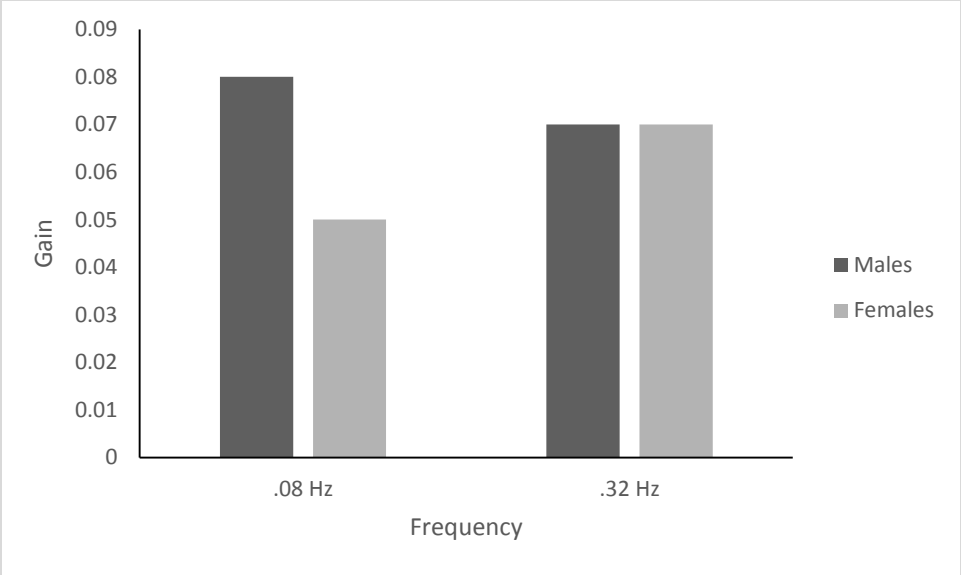


Figure 8. The mean gain values of male and female participants during the Visual Suppression subtest.

interaction effect between frequency and gender, F (1, 26) = .001, p = .98 and no significant interaction effect between the frequency and VO_2max, F (1, 26) = .088, p = .769, indicating that frequency differences are unaffected by VO_2max and gender.

Figure 9 shows the relationship between different fitness levels on gain values at different frequencies during the VS subtest. Examination of Figure 9 shows no clear interactions between gain values at different fitness levels. A 3 x 2 (fitness level x frequency) mixed ANOVA found no significant effects of fitness level, indicating no differences in gain value at both frequencies when fitness level varies, F (2, 26) = 2.825, p = .078. There was a significant effect of frequency, indicating that gain values were significantly different at each frequency during the SHA subtest, F (1, 26) = 11.699, p = .002. There was not a significant interaction effect between frequency and fitness level, F (2, 26) = 1.779, p = .189.

Symmetry. Figure 10 shows the difference between symmetry values at different frequencies for males and females. Examination of this figure shows no apparent differences between males and females in symmetry values at either frequency. A 2 x 2 (gender x frequency) mixed ANOVA and a fitness level covariate was conducted to analyze differences in visual suppression frequencies. There was no significant effect of gender. This indicates symmetry values at either frequency were generally the same between male and female participants, F (1, 26) = .130, p = .721. VO_2max values were non-significant, indicating that symmetry values were generally the same at all VO_2max values, F (1, 26) = .244, p = .625. There was no significant interaction effect between frequency and gender in symmetry values, F (1, 26) = .005, p = .942 and no significant

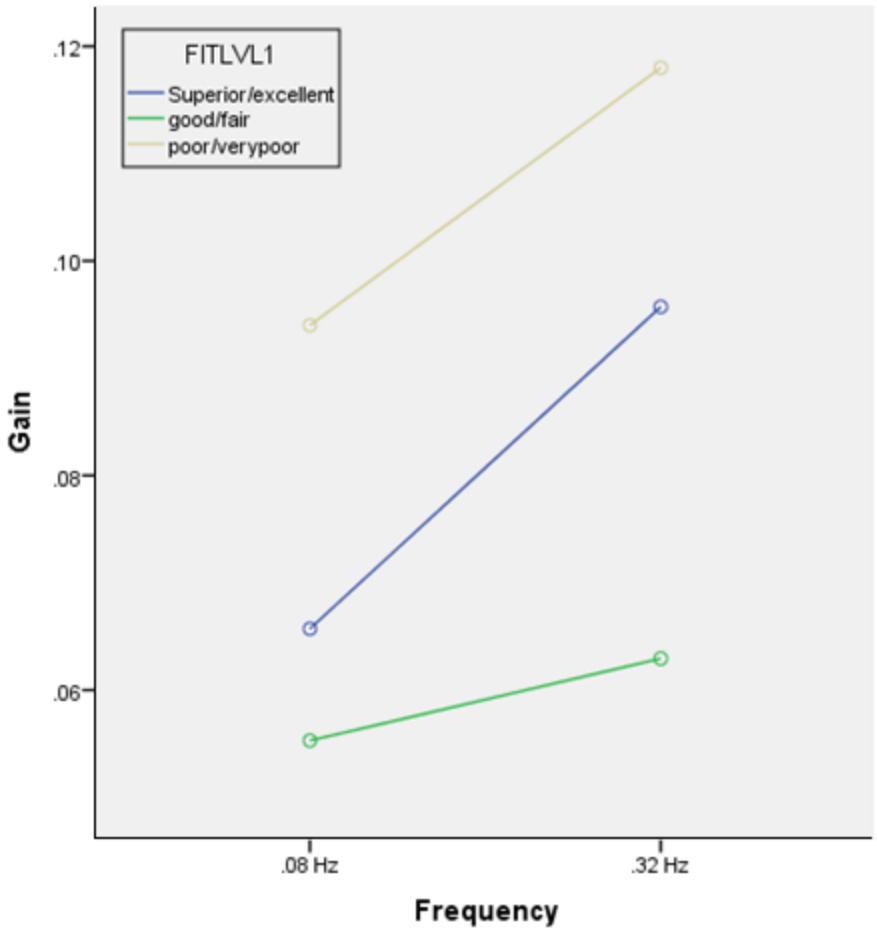


Figure 9. Mean gain values at various different fitness levels during the Visual Suppression subtest.

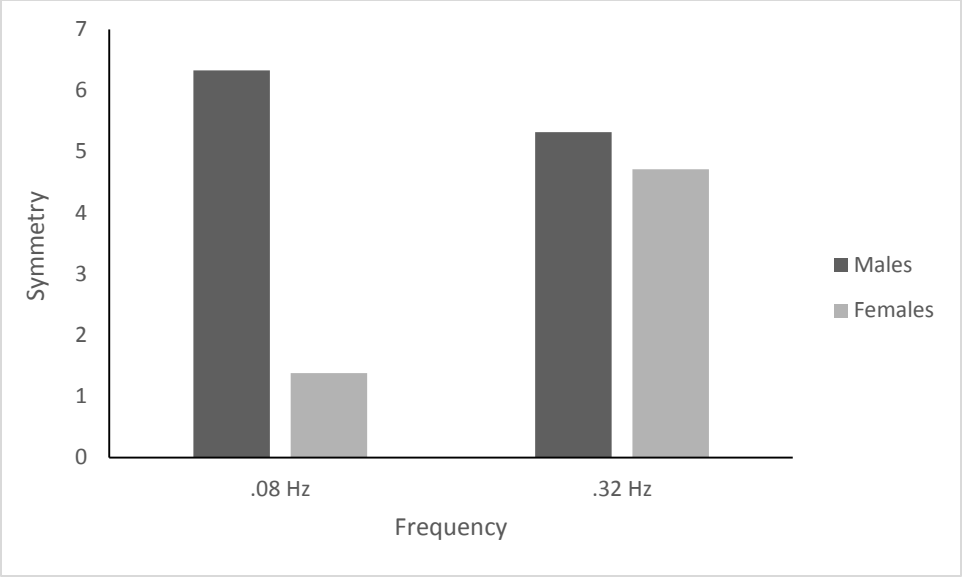


Figure 10. The mean symmetry values of male and female participants during the Visual Suppression subtest.

interaction effect between frequency and VO_2max, F (1, 26) = .010, p = .920, indicating that frequency differences are unaffected by VO_2max and gender.

Figure 11 shows the differences in fitness level on symmetry values at two frequencies. Examination of Figure 11 reveals no apparent interaction between fitness level and symmetry values. A 3 x 2 (fitness level x frequency) mixed ANOVA was used to analyze fitness level on symmetry values during visual suppression. There were no significant effects of fitness level, F (2, 26) = .234, p = .793. This indicates that there is no difference in symmetry values at either frequency when the fitness levels vary. There was not a significant effect of frequency, indicating that symmetry values are essentially the same at both frequencies, F (1, 26) = .106, p = .747. There was not a significant interaction effect between frequency and fitness level, F (2, 26) = .907, p = .416.

Phase. Figure 12 shows male and female phase values at different frequencies during the VS subtest. Examination of this figure shows no clear differences of gender on the phase values. A 2 x 2 (gender x frequency) mixed ANOVA with a covariate of VO_2max value was conducted to determine gender and VO_2max differences in phase values. There was no significant effect of gender, indicating no differences between phase values for males and females, F (1, 26) = .227, p = .638. VO_2max was non-significant, indicating that phase values were generally the same at all fitness levels, F (1, 26) = .329, p = .571. There was no significant interaction effect between frequency and gender in the phase values, F (1, 26) = .052, p = .821. There was no significant interaction effect between frequency and VO_2max value, F (1, 26) = .060, p = .808, indicating that frequency differences are unaffected by VO_2max and gender.

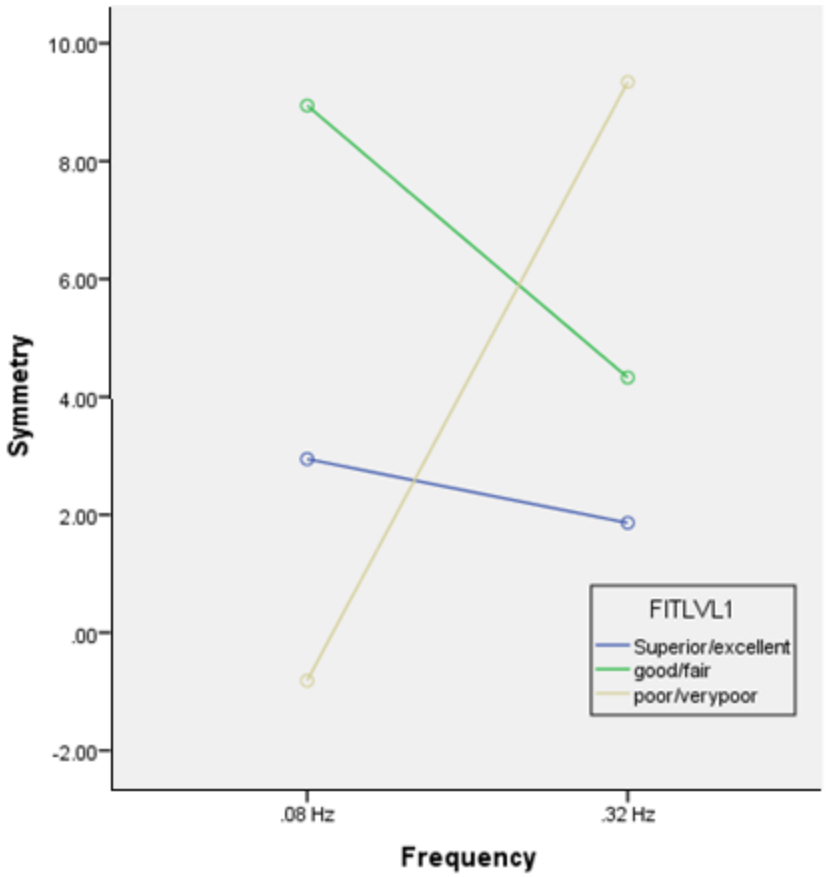


Figure 11. Mean symmetry values at various different fitness levels during the Visual Suppression subtest.

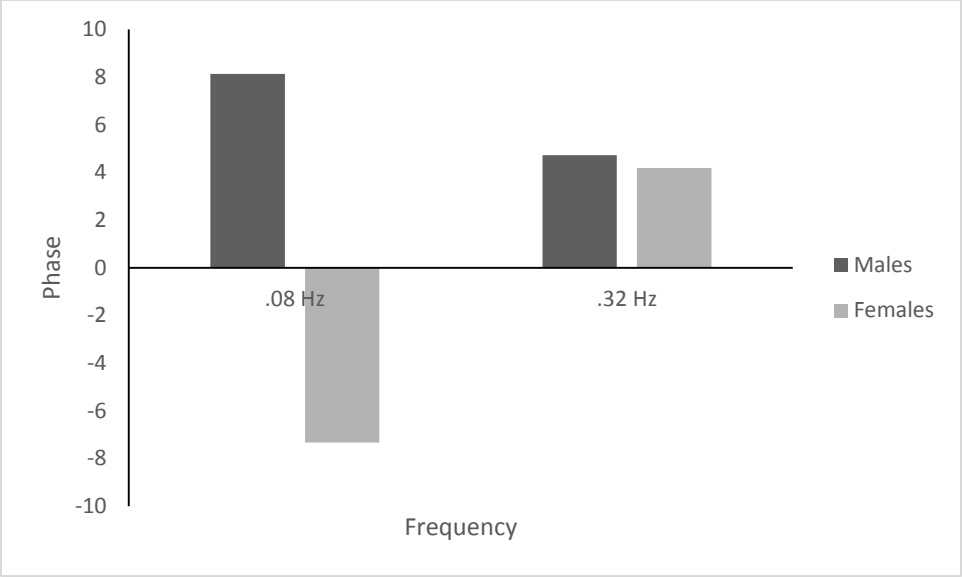


Figure 12. The mean symmetry values of male and female participants during the Visual Suppression subtest.

Figure 13 shows the relationship between fitness levels on phase values at different frequencies during the VS subtest. Examination of Figure 13 indicates no apparent interaction between fitness levels on phase values. A 3 x 2 (fitness level x frequency) mixed ANOVA was conducted to analyze effects of categorical fitness level on phase values at two frequencies. There was no significant effect of fitness level, F (2, 26) = 2.679, p = .087. This indicates that fitness level does not affect the phase values at any frequency. There was a non-significant effect of frequency, F (1, 26) = .485, p = .492. This indicates that phase values are generally the same at each frequency during the visual suppression subtest. There was not a significant interaction effect between frequency and fitness level, F (2, 26) = .003, p = .997.

Gain Reduction. Figure 14 shows male and female gain reduction percentages at .08 and.32 Hz during the VS subtest. Examination of Figure 14 shows a possible difference between males and females on gain reduction in both frequencies. It seems that females have a larger gain reduction percentage. A 2 x 2 (gender x frequency) mixed ANOVA with a covariate of VO_2max value was conducted to determine gender and VO_2max differences in gain reduction percentages. Conversely from the descriptive statistics, the ANOVA showed no significant effect of gender, indicating no differences between gain reduction for males and females, F (1, 26) = 2.543, p = .123. VO_2max was non-significant, indicating that gain reduction was generally the same at all fitness levels, F (1, 26) = .218, p = .644. There was no significant interaction effect between frequency and gender in the phase values, F (1, 26) = .038, p = .846. There was no significant interaction effect between frequency and VO_2max value, F (1, 26) = .750, p = .830, indicating that frequency differences are unaffected by VO_2max and gender.

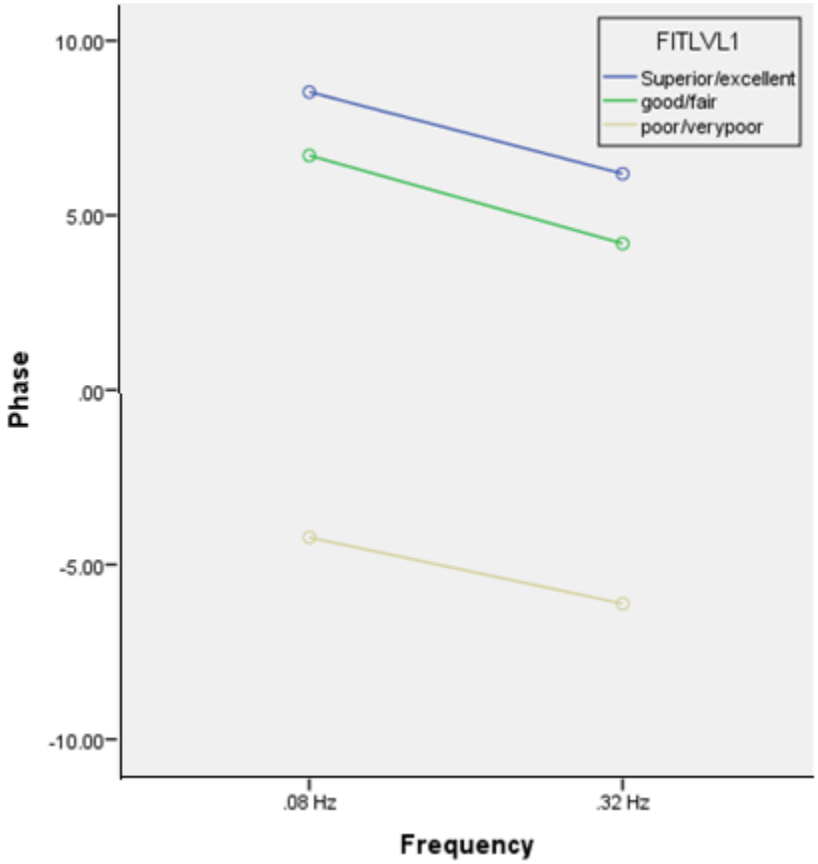


Figure 13. Mean gain values at various different fitness levels during the Visual Suppression subtest.

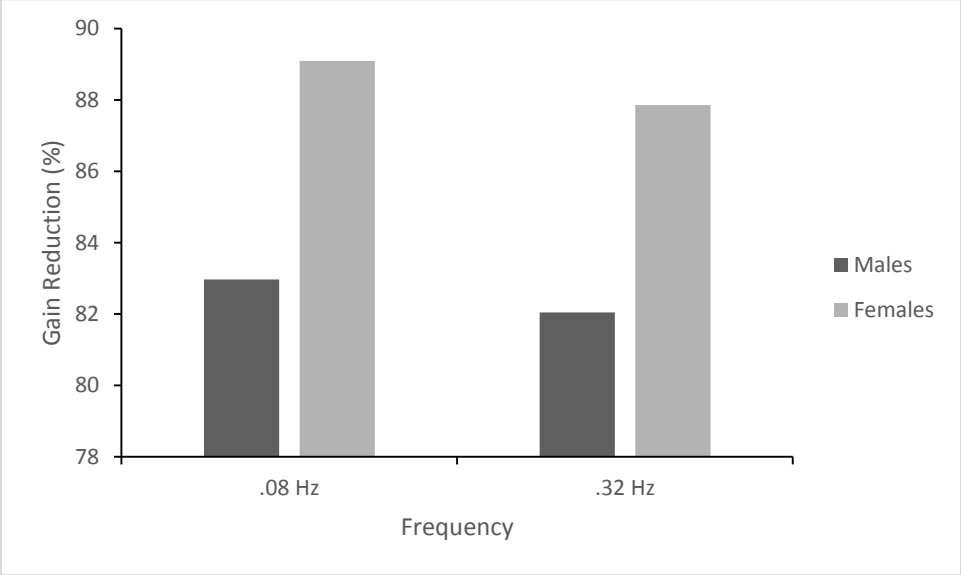


Figure 14. The mean gain reduction (%) of male and female participants during the Visual Suppression subtest.

Figure 15 shows the relationship between fitness levels on gain reduction at different frequencies during the VS subtest. Examination of Figure 15 shows no apparent interaction between fitness levels on the gain reduction. A 3 x 2 (fitness level x frequency) mixed ANOVA was conducted to analyze effects of categorical fitness level on gain reduction at two frequencies. There was no significant effect of fitness level, F (2, 26) = 2.741, p = .083. This indicates that fitness level does not affect the gain reduction at any frequency. There was a non-significant effect of frequency, F (1, 26) = 2.031, p = .166. This indicates that gain reduction percentages are generally the same at each frequency during the visual suppression subtest. There was not a significant interaction effect between frequency and fitness level, F (2, 26) = .740, p = .487.

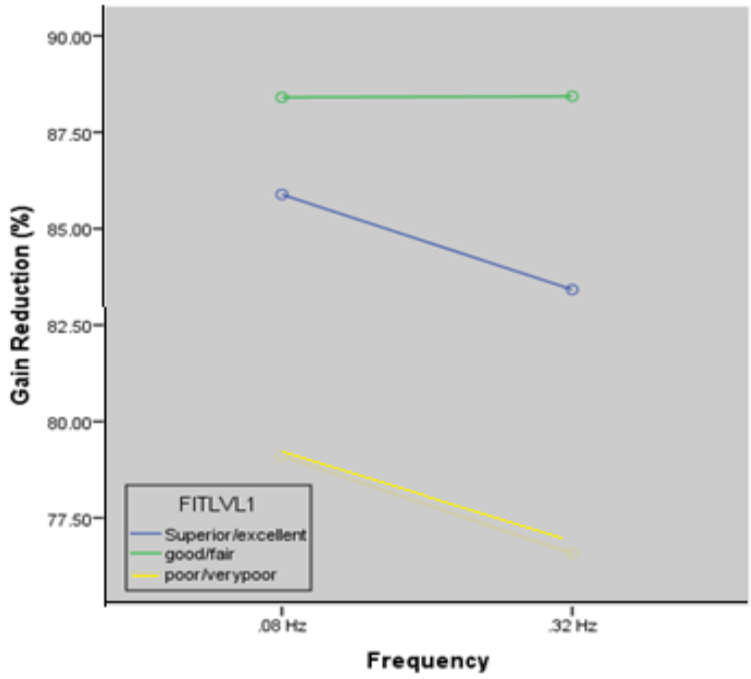


Figure 15. Gain reduction at various different fitness levels during the Visual Suppression subtest.

Chapter 5

Discussion

Rotational chair testing is used frequently in vestibular clinics to assess vestibular function. Different subtests of the rotary chair yield different responses of the vestibular system. Specifically, the SHA and VS subtests evaluate the VOR (Ahmed, Goebel & Sinks, 2009). During SHA, the head moves with the chair at different frequencies resulting in compensatory eye movements. During the VS subtest, the eyes stay focused on a light while the chair moves, resulting in little or no eye movements. Different parameters including gain, symmetry, phase, and gain reduction are used to evaluate how the eyes move, and thus, how the VOR functions.

When a new piece of equipment is introduced to a vestibular clinic, normative data need to be collected to help audiologists differentiate between normal and abnormal VOR function and possible vestibular pathologies (Maes et al., 2008). This study has gathered normative data for the new rotary chair acquired by the TU-HBC in August, 2012. Gender and fitness level effects on the VOR were also analyzed for this study to determine if they affected the vestibular test results.

Summary of Test Findings

Frequency Effect. There were significant effects of frequency on gain, symmetry, and phase during the SHA subtest. Previous research has indicated VOR gain and phase are weakest at the lower frequencies and strongest at the higher frequencies (Barin, 2009; Fife et al., 2009). This same pattern is confirmed in the present study. Furthermore, when gain and phase are affected by frequency, symmetry was also affected. In a normal vestibular system, conjugate eye movements result from continuous

head movements. Therefore, if gain or phase differ at specific frequencies, the symmetry of the eye movements will also differ and will move together at the speed of the head movements.

There was a significant effect of frequency on gain during the VS subtest. This supports previous research stating that VOR gain is stronger at higher frequencies (Barin, 2009; Fife et al., 2009). However, there were no significant effects of frequency on phase or symmetry during the VS subtest. This finding could be consistent with the theory that the eyes are stable during this test, and therefore show minimal to no eye movements as the chair moves. For example, when the head is in motion, an individual should be able to suppress compensatory eye movements and fixate on a target (Hain & Rudisill, 2008). The difference between gain values during SHA and VS, at the same frequency, results in a gain reduction percentage. This percentage reveals how much the compensatory eye movements were suppressed. A gain reduction percentage in the range of 75-90% results in an individual's ability to suppress the VOR to be within normal limits (Jacobson et al., 2012).

Gender Effect. There were no gender effects of the VOR for any of the parameters, gain, symmetry, or phase, at any frequency in either the SHA or visual suppression subtests. There has been controversy in the literature about gender effects specifically that women tend to fall more frequently and have more balance dysfunction. However, most gender effects are seen in the older population (Vereek et al. 2008). Therefore, the findings in the present study could be specific to this age group or the rotary chair tests conducted, and not related to the younger participants tested in the current study.

Fitness Level Effects. There were no fitness level effects on the VOR (SHA or VS suppression subtests) for any of the three parameters at any frequency. No previous research has evaluated fitness level on the vestibular system. Therefore, the findings in the present study should be evaluated further with different vestibular testing and other measures of fitness level.

Clinical Significance

Because this normative data set from the present study is similar to previous findings of rotary chair testing (Brey et al., 2008), the data appear to represent a valid baseline of normal outcomes audiologists can use in the TU-HBC, when testing individuals aged 18-30 years old. Appendix I summarizes the normative data of the SHA and VS subtests for all participants. The chart summarizes the range of normal results and one and two standard deviations. If an individual's values are within the given range, the results of the SHA and VS subtests yield within normal results. This chart can be used by audiologists in the clinic to evaluate normal and abnormal results of the VOR during these two subtests.

Further, the results of this study suggest no gender or fitness level differences in the VOR at various frequencies for the SHA and VS subtests. Therefore, this normative data set can be used for all individuals aged 18-30, regardless of gender or fitness level.

Limitations of the Present Study and Future Research

Sample Size. This present study was limited to 31 individuals, with more female participants compared than males. In future research, a larger population with a more balanced representation of females and males and a wider range of fitness levels should be evaluated.

Recruitment. All participants in the present study were recruited through email and word of mouth from Towson University's student population. The age of the participants ranged from 20-26 years old and affected external validity, because this normative data set can only be referenced for this age range. Also, fitness levels could have been more varied with a larger age range. In the future, a larger age range should be evaluated.

Rotary Chair. The rotational chair's frequency output is controlled and could potentially lead to unnatural movements of the head. For example, the highest frequency, 1.75 Hz, elicits a rapid head movement that individuals do not commonly make in everyday life. Therefore, an individual with normal VOR function might not produce a measured VOR exactly at the speeds of the rotational chair. Responses of the VOR in this study could be heightened or diminished due to the unnatural head movements elicited by the equipment. Future research should combine several different vestibular tests to evaluate any gender or fitness level differences on the VOR.

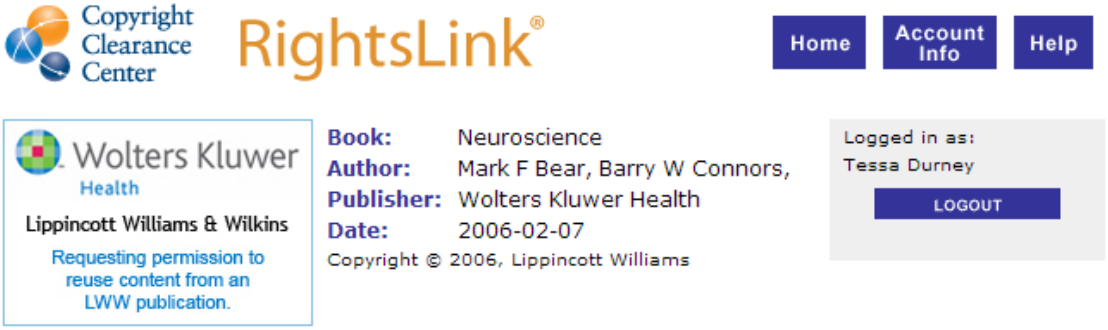
Vestibular Testing. The present study used only two subtests, SHA and VS of the rotary chair, to assess the VOR, the horizontal semicircular canals, and the central pathways of the vestibular system. There are several other vestibular tests that evaluate other parts of the vestibular system such as the vestibular evoked myogenic potential (VEMP), electronystagmography (ENG), Dix-Hallpike maneuvers, and Computerized Dynamic Posturography (CDP). Therefore, further research should be conducted using other vestibular tests to evaluate any gender or fitness level effects of the vestibular system.

Future Research. Future research should focus on other subtests of the rotary chair, including the Step Velocity Test and the Subjective Visual Vertical subtest, resulting in a complete normative data set for the rotary chair at the TU-HBC. Also, future research should focus on normative data sets specifically for athletes. This data will be used to compare norms between athletes and non-athletes to determine if there are any true differences between these populations.

Conclusions

Collecting normative data is essential for new rotary chairs when they are installed in audiology clinics. These data provides a baseline that audiologists can use to interpret VOR function during the SHA and VS subtests. Further, these results will help audiologists diagnose normal and abnormal vestibular function, specifically of the VOR. Frequency specific results from the SHA and VS subtests, including the gain, phase, and symmetry values, were comparable to a normative data set established by Maes and her colleagues (2008) and from Mayo Clinic Rochester (Goulson, McPherson & Shepard, 2014), suggesting the data are valid. Gain reduction percentages for both .08 Hz and .32 Hz were also similar to the Mayo Clinic normative data set. They found an 82% gain reduction in both frequencies, similar to 85-86% found in the present study (McPherson & Brey, 2005). The current study indicated neither gender nor fitness affected the VOR. The data analysis revealed no gender or fitness level differences in the normative data. Therefore, the same baseline data set developed in this study can be used for both genders and individuals with different levels of fitness, aged 18-30.

APPENDIX A



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BACK CLOSE WINDOW

APPENDIX B

TOWSON UNIVERSITY

APPROVAL NUMBER: 14-A096

To: Tessa Durney
8000 York Road
Towson MD 21252

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

Date: Thursday, June 26, 2014

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

APPROVED JUN 26 2014 TOWSON IRB

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 sinsusoidal 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

APPENDIX C

Questionnaire for participants

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

APPENDIX D

1. Has your doctor ever said that you have a heart condition and that you should only do physical activity recommended by a doctor?
2. Do you feel pain in your chest when you do physical activity?
3. In the past month, have you had chest pain when you were not doing physical activity?
4. Do you lose your balance because of dizziness or do you ever lose consciousness?
5. Do you have a bone or joint problem (for example, back, knee or hip) that could be made worse by a change in your physical activity?
6. Is your doctor currently prescribing drugs (for example, water pills) for your blood pressure or heart condition?
7. Do you know of any other reason why you should not do physical activity?

APPENDIX E

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	Antivert, Meclizine, Scopolamine, etc.
Antihistamines/decongestants	Benadryl, Allegra, Claritin, etc.
Anti-Nausea	Dramamine, Bonine, Compazine, etc.
Tranquilizers	Valium, Xanax, Ativan, Sarafem, 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 F

"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 VO2max was greater than 45 ml · kg−1 · 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 beats · 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 steps · min−1 necessary for the test on women. For men, set the metronome at 96 beats · min−1 and thus 24 steps · min−1.

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

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 7.3*b*). Begin counting at exactly 3:05 and count for 15 s (i.e., to 3:20).

Step 8: Calculate the predicted VO2max by using the recovery HR in the equations below, where HR is beats · min−1.

Men: VO2max (ml · kg−1 · min−1) = 111.33 - (0.42 × HR)
Women: VO2max (ml · kg−1 · min−1) = 65.81 - (0.1847 × HR)
Step 9: Record your own data on the individual data sheet and on the group data sheet".
(Haff & Dumke, 2012)

APPENDIX G

Examples of Mental Alerting Tasks:

- Names of states and capital in the United States
- Various sports teams
- Names of holidays
- Names of flowers or trees
- Things to buy in the produce section and/or dairy section of the grocery store
- Names that start with different letters of the alphabet
- Places to visit on vacation
- Things to see at the beach

APPENDIX H

	Fitness Level Category	VO_2max	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 I

NORMATIVE DATA TABLE

Sinusoidal Harmonic Acceleration

Frequency	Mean (+/- 1 SD)			Mean (+/- 2 SD)		
	Gain	Symmetry	Phase	Gain	Symmetry	Phase
.01 Hz	.28 - .48	-9.72 - 12.76	34.96 - 48.3	.18 - .58	-20.96 - 24	28.29 - 54.97
.02 Hz	.34 - .52	-5.97 - 12.57	18.53 - 28.81	.25 - .61	-15.24 - 21.84	13.39 - 33.95
.04 Hz	.38 - .64	-4.48 - 12.44	7.47 - 15.57	.25 - .77	-12.94 - 20.9	11.52 - 19.62
.08 Hz	.36 - .64	-12.07 - 11.35	-1.24 - 6.08	.22 - .78	-23.78 - 22.76	-4.9 - 9.74
.16 HZ	.39 - .67	-10.43 - 7.61	-1.19 - 4.33	.25 - .81	-19.45 - 16.63	-3.95 - 7.09
.32 Hz	.45 - .69	-7.5 - 8.12	-1.59 - 4.65	.33 - .81	-15.31 - 15.93	-4.71 - 7.77
1.28 Hz	.75 - .99	-3.59 - 7.21	-11.84 - 11.16	.63 - 1.11	-8.99 - 12.61	-23.34 - 22.66
1.75 Hz	.58 - 1.0	-10.55-11.03	-33.17 - 2.95	.37 - 1.21	-21.34 - 21.82	-51.23 - 21.01

Visual Suppression

Frequency	Mean (+/- 1 SD)			Mean (+/- 2 SD)		
	Gain	Symmetry	Phase	Gain	Symmetry	Phase
.08 Hz	.02 - .1	-18.14 - 25.96	-35.72 - 34.46	-.02 - .14	-40.19 - 48.01	-70.81 - 69.55
.32 Hz	.03 - 13	-9 - 19.58	-10.99 - 17.23	-.02 - .18	-23.29 - 33.87	-25.1 - 31.34

	Gain Reduction (%)	
.08 Hz	77.92 - 95.14%	69.31 - 103.75%
.32 Hz	74.79 – 96.03%	63.87 – 106.65%

APPENDIX J

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, this 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

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CURRICULUM VITA

NAME: Tessa A. Durney

[redacted]

PROGRAM OF STUDY: Audiology

DEGREE AND DATE TO BE CONFERRED: Doctor of Audiology (Au.D.), 5/2016

SECONDARY EDUCATION: Academy of the Holy Cross—Kensington, MD 20895

Collegiate institutions attended	Dates	Degree	Date of Degree
Towson University—*Towson, MD*	8/2008 - 5/2012	B.S.	5/2012
University of Newcastle—*Newcastle, Australia*	2/2011 – 6/2011	n/a	n/a
Towson University—*Towson, MD*	8/2012 - 5/2016	Au.D.	Anticipated 5/2016

PROFESSIONAL POSITIONS HELD:

****All were clinical internships in accordance with Towson University's Audiology Doctoral Program**

St. Agnes Hospital
3449 Wilkens Ave
Baltimore, MD 21229
Doctoral Student Clinician, February 2015—May 2015

University of Maryland Medical Center
16 S. Eutaw Street #400
Baltimore, MD 21201
Doctoral Student Clinician, January 2015

Lincoln Intermediate Unit #12
York Learning Center
300 East 7th Avenue
York, PA 17404
Doctoral Student Clinician, September 2014—December 2014

ENTAA Care
203 Hospital Drive, Suite 200
Glen Burnie, MD 21061
Doctoral Student Clinician, January 2014—July 2014

Towson University Speech, Language and Hearing Center
One Olympic Place
Towson, MD 21204
Doctoral Student Clinician, January 2013—December 2013