James Madison University
JMU Scholarly Commons

Spring 2018

Does EMG monitoring in a CVEMP matter?

Kimberly Fleck
James Madison University

Follow this and additional works at: https://commons.lib.jmu.edu/honors201019

⚫ Part of the Speech and Hearing Science Commons, and the Speech Pathology and Audiology Commons

Does EMG Monitoring in a cVEMP Matter?

_____

An Honors College Project Presented to

the Faculty of the Undergraduate

College of Health and Behavioral Sciences

James Madison University

_____

by Kimberly Sierra Fleck

May 2018

Accepted by the faculty of the Department of Communication Sciences and Disorders, James Madison University, in partial fulfillment of the requirements for the Honors College.

FACULTY COMMITTEE: HONORS COLLEGE APPROVAL:

_____   _____
Project Advisor: Erin Piker, Ph.D.   Bradley R. Newcomer, Ph.D.,
Assistant Professor, Ph.D.   Dean, Honors College

_____
Reader: Christina Kuo, Ph.D.
Assistant Professor, Communication Sciences and
Disorders

_____
Reader: Lincoln Gray, Ph.D.
Professor, Communication Sciences and Disorders

PUBLIC PRESENTATION

This work is accepted for presentation, in part or in full, at Honors Symposium on April 18, 2018.

Contents

Lists of Tables and Figures

Acknowledgements

I would like to thank Dr. Piker for giving me an opportunity to work in her lab as well as her continued support and mentoring throughout this project. She has provided me with much guidance throughout my time working with her. I would like to also thank my readers, Dr. Gray and Dr. Kuo, for their guidance. A big thank you to Paris Atabek for showing me the ropes in the vestibular lab. To the honors students fulfilling the second portion of this study, good luck and I hope you find the answers that we are looking for.

Abstract

To determine if EMG monitoring or the use of amplitude normalization would significantly reduce the amplitude variability and amplitude asymmetry of the cVEMP in children ages 3 and under, we first needed to create a control group with young, healthy adults to compare the pediatric group to. We also wanted to replicate earlier studies that showed EMG monitoring and amplitude normalization does not have an impact on the VEMP in young, healthy adults. We tested two different positions, sitting and supine. Supine is the optimal position to generate EMG, but we wanted to have control data in case the pediatric group is unable or unwilling to be in the supine position for the test. Our findings were similar to previous studies and we know that young, healthy adults can generate equal EMG on both their left and right sides, but clinical populations like young children may not be able to. Therefore, EMG monitoring can be a critical aspect of a cVEMP in cases where a child may need to be tested.

Purpose

It is known that the amplitude of the cervical vestibular evoked myogenic potential (cVEMP) is directly proportional the amount of electromyographic (EMG) activity generated in the sternocleidomastoid muscle (SCM). However, previous studies have suggested that in young, healthy, populations it is not necessary to monitor EMG or correct for EMG levels. In other words, the amplitude and amplitude asymmetry between ears of the cVEMP is not significantly altered when EMG is monitored compared to when it is not, at least in young, healthy adults. Our long-term goal is to determine whether the use of EMG monitoring or the use of amplitude normalization techniques would significantly reduce the amplitude variability and amplitude asymmetry of the cVEMP in children ages 3 and under. The objective of this project, which represents the first step to reaching the long-term goal, is as follows:

1.) To replicate previous studies showing that EMG monitoring and amplitude normalization does not have a significant effect on VEMP parameters in young, healthy adults

2.) Collect control group data, in healthy adults, that will be used in subsequent studies as a comparison to a pediatric group

Hypothesis

For our first objective, we hypothesize that in young adults there will be no statistically significant differences in cVEMP outcomes between the following 3 recording conditions: no EMG monitoring, EMG monitoring only, EMG monitoring with a visual hand-held monitor. Further, there will be no differences in the corrected cVEMP amplitude (i.e. amplitude normalization) between the 3 recording conditions.

For our second objective, we chose to collect our control group data in two positions, sitting and supine. Studies suggest maximum EMG contraction when supine, but some children may be too scared to lay down for the test. They may be more likely to complete the test if they are sitting upright in their parent's lap, turning their head. For comparison purposes, we wanted to collect control group data in this position also. Further, we wanted to confirm that adequate EMG could be generated in the sitting position. Descriptive findings will be given for this objective.

Introduction

What is a VEMP?

VEMPs are vestibular-evoked myogenic potentials which are short-latency electromyograms (EMGs) that can be evoked by acoustic or vibratory stimuli (Akin 2004). When the evoked response is recorded over the sternocleidomastoid muscle, it is referred to as a cervical VEMP or cVEMP. Whereas most vestibular testing is limited to an assessment of the semicircular canals, cVEMPs provide unique information about the integrity of the saccule and inferior vestibular nerve (Akin 2004). As such, cVEMPs have been used for a variety of vestibular and neurological disorders. cVEMPs were first elicited using click stimuli. However, it has been found that low frequency tones, such as 500 Hz or 750 Hz, produce larger, and more reliable, responses (Piker et al. 2013).

The cVEMP represents a reflex that is a portion of the vestibulocollic reflex (Jacobson 2016). The vestibulocollic reflex begins in the saccule end organ, travels through its afferent pathway via the inferior vestibular nerve to the vestibular nucleus, then travels through its efferent pathway via the medial vestibulospinal tract, which carries the signal to the nucleus of cranial nerve XI and to the sternocleidomastoid muscle (SCM). The vestibular-evoked response is an inhibition of the ipsilateral SCM that involuntarily happens when a stimulus is introduced, such as an intense air conduction stimulus, that can translate the otolith organs (Jacobson 2016). A cVEMP is then recorded by placing a surface electrode on the SCM. In addition to the functional integrity of the saccule and the vestibulocollic reflex pathway, the amplitude of the cVEMP is directly affected by both the intensity of the air conduction stimulus and the tonic contraction of the SCM (i.e. EMG; Akin et al. 2004). The greater the intensity of the stimulus, and the greater the contraction of the SCM and resulting EMG level, the larger the cVEMP

amplitude. Since the most useful parameter, for diagnostic purposes, of the cVEMP is the difference in amplitude between ears, it is key that the EMG from the right and left SCM is equal. If not, then the cVEMP amplitude will be asymmetrical.

VEMP and EMG Relationship

The cVEMP represents an inhibition of the SCM in response to vestibular stimulation. Thus, the SCM must first be tonically contracted in order for the cVEMP to be recorded and the amplitude of the cVEMP is in direct relation to the amount of EMG generated from the SCM. In fact, if no EMG is generated there will be no cVEMP response (regardless of vestibular function) and as EMG levels increase so does the amplitude of the cVEMP in a linear fashion (Akin et al. 2004). For this reason, to obtain an accurate reading of the cVEMP, early researchers strongly recommended that the SCM be monitored to determine how much, or little, the muscle contracts. Without a baseline measurement of the SCM, it is difficult to compare the amplitude from one ear to another and to compare cVEMP responses from one individual to another. For example, the main outcome measure from the cVEMP used for diagnostic purposes is the difference in amplitude between the right and left ears. This is called interaural amplitude asymmetry and is calculated as follows: 100 * (Left amplitude – Right amplitude)/ (Left amplitude + Right amplitude). In order for this calculation to accurately reflect vestibular function, EMG must be equal between the right and left side. If one SCM produces larger EMG, the resulting cVEMP amplitude will be significantly larger and there will be an amplitude asymmetry. This asymmetry would be due to the SCM and would not reflect asymmetrical vestibular function; although the asymmetry may be erroneously interpreted as asymmetrical vestibular function.

To monitor the SCM, there are two possible techniques. The first is a direct control of the neck muscle activity through monitoring of the EMG and maintaining the contraction within a specified EMG window. The second is the calculation of a corrected reflex amplitude by dividing the average EMG into the amplitude, a technique known as amplitude normalization (Akin 2004).

It is well accepted that the amplitude of the cVEMP is directly related to the amount of EMG generated in the SCM (Akin et al. 2004). It is also accepted that EMG monitoring and amplitude normalization are effective techniques for controlling or correcting EMG (Rosengren et al 2015). However, until recently, there were no commercially available evoked potential systems equipped to monitor EMG; thus this was a practice largely done in research labs using additional equipment not easily accessible to most clinicians. To justify the lack of EMG monitoring in clinical population studies, several researchers attempted to show that when using the optimal recording position, supine with the head turned and lifted, EMG monitoring and amplitude normalization did not have a large effect on the absolute cVEMP amplitude or amplitude asymmetry (McCaslin et al. 2013; Tillburg et al. 2014). Although these studies did not find statistically significant difference in the monitoring condition versus the no monitoring condition, there was a major limitation to the study design. That is, all participants in these studies were young, healthy, adult volunteers. It is quite possible that when in a supine position with the head lifted and turned (i.e. the "optimal" cVEMP recording position), young adults easily and consistently generate equivalent EMG from the right and left; thus, monitoring or not monitoring the EMG does not make a difference. This is a limitation because most clinical populations are not young healthy adults. In fact, they tend to be older, frail adults or young children. This is critical in older populations who may have asymmetrical musculature or

difficulty maintaining an SCM contraction. This is also critical in pediatric populations who may be too scared to lay down for the test and need to sit upright in their parent's lap, or, for lack of a better term, too "wiggly" to maintain the position of optimum SCM contraction. Furthermore, in young children under the age of 4, cVEMPs are one of the few objective tools available for assessing vestibular function (O'Reilly, 2013). For this reasons, the recording parameters of the cVEMP in pediatric populations must be systematically evaluated. To date, no investigator has shown, or not shown, that EMG monitoring is essential in very young children.

Disorders in pediatric populations

For balance to be maintained, three aspects must be in sync: vision, vestibular function, and proprioception. If any one of these aspects are impaired, balance could be impacted (O'Reilly 2013). During infancy and preschool years, changes in balance function develop quickly. A vestibular impairment may contribute to the child not meeting their balance/motor milestones. In fact, a vestibular impairment is typically only noticed at these young ages because there are certain milestones that are not met such as standing and walking (O'Reilly 2013).

Although less common than in adults, there are some diseases that can cause vestibular dysfunction in pediatric populations. Meniere's disease has a less than 4% occurrence in children but has several symptoms that can be extremely debilitating which include vertigo, ear pressure, hearing loss and tinnitus (O'Reilly 2013). Recurrent vestibulopathy can also occur and is characterized by several episodes of vertigo that can last from minutes to hours. Pediatric patients with recurrent vestibulopathy can also have a later diagnosis of Meniere's disease or benign paroxysmal positional vertigo (O'Reilly 2013). Head trauma is a more common occurrence in young children (CDC 2017). Trauma can cause headaches, cognitive impairments

and even problems with sleeping. Regardless of the type of head injury (blunt or penetrating), children can experience vertigo, impairments of the vestibular system, and nausea (O'Reilly 2013). Another disease that is more common in adults, but can occur in children, is vestibular neuritis. Children present with the same symptoms as adults such as vertigo and vomiting that can last weeks. Otitis media is extremely common with children and prolonged or excessive otitis media can be a source for balance dysfunction as well. There has been evidence showing that following the resolution of a middle ear effusion, the vestibular system can remain impaired (O'Reilly 2013).

Vestibular impairments can occur with or without hearing impairments, but for children with hearing loss the vestibular system is at risk for dysfunction due to the proximity to the cochlea and the similarities to the end organs. It is important to understand the relationship between the vestibular system and deafness because sensorineural hearing loss is the most common congenital impairment (CDC 2017). Deafness occurs in 1.4 of every 1000 live births in the United States (CDC 2017). A percentage of these children with deafness will also have a vestibular dysfunction that will need identification. (O'Reilly 2013).

While the incidence of vestibular impairments is less common in children, the effects can be significant nonetheless. It is important to assess children's vestibular functioning for at least two reasons. First, it can determine the child's functional status and help to define the appropriate treatment. Second, it can determine whether their symptoms (i.e. vertigo) are caused by a vestibular lesion or something more sinister such as a neurological impairment (i.e. brain tumor) (O'Reilly 2013).

cVEMPS in Children

Not all adult vestibular function testing has been, or can be, adapted for children. In fact, the most commonly used vestibular diagnostic test, the caloric test, is not recommended for children under the age of 6-7 years. Fortunately, cVEMPs are relatively fast, easy, and non-invasive and are one of the few objective vestibular assessments that have been successfully done in children as young as one month in age (O'Reilly 2013). The air conduction stimulus used to elicit the cVEMP can be the same, however, recent reports suggest using a slightly lower SPL stimulus in young children to avoid damaging the cochlea (Rodriguez et al. 2017). The EMG activity on the SCM is recorded in the same way as in adults using surface electrodes.

As with adults, to accurately record the cVEMP in children it is important to maintain regular contraction of the SCM. This can be difficult in very young children. The optimal position is supine, head lifted, and turned away from the stimulus ear to contract the SCM. In young children, they may also sit on their care-givers lap and turn their heads while sitting upright. To date, no one has examined whether sitting with the head turned generates enough EMG in young children to record the cVEMP, and no one has examined whether young children can behaviorally complete the task. That is, can a young child hold their head in that position for 30-60 seconds? If not, EMG monitoring would be extremely important as it would allow us to make corrections for EMG changes throughout testing and obtain a more accurate test result.

Participants

The participants were 11 young, healthy adults recruited from the JMU community. There were 9 females and 2 males. Their ages ranged from 20 to 23 with a mean age of 20.7. The participants had tympanometry and otoscopy done on the same day of testing to confirm that there are no middle ear issues that could skew the results of the cVEMP. Participants generated at least a 50 µV RMS tonic EMG activity from both the left and the right SCM.

cVEMP Recording

Disposable silver/silver-chloride electrodes were applied to the surface of the skin using a conventional clean electrode preparation technique with impedances < 10 mm Ω and interelectrode impedances < 5 mm Ω. The ground electrode was placed in the middle of the forehead. The reference was applied to the middle of the chest above the clavicle. The non-inverting electrode was applied to the upper third of the SCM and the EMG monitoring electrode was placed directly beneath. Figure 1 and 2 below show the placements of the electrodes and the contraction of the SCM.
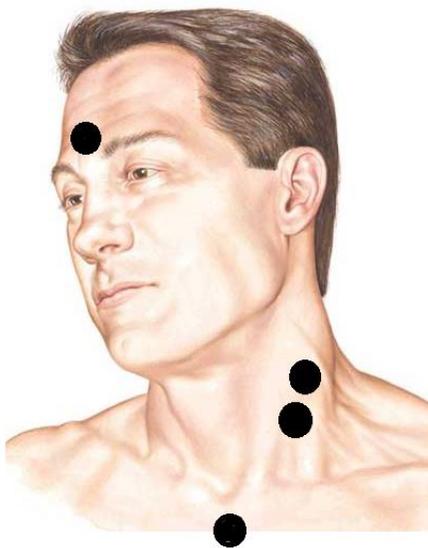

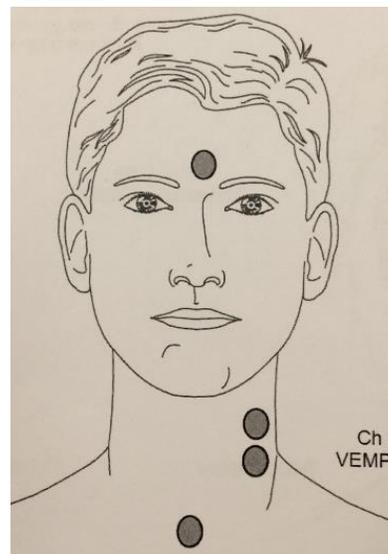**Figure 1 Electrode Placement with SCM Fixed**

Figure 2 Electrode Placement without SCM Flexed

14

Testing was completed in two different seating positions: 1) supine in a reclined chair, 2) sitting upright in the chair. The subjects were instructed to either lift and turn their head opposite of the ear that is being stimulated, or, if sitting to simply turn their head.

The stimulus was presented monaurally through Etymotic ER-3A insert earphones and consisted of a 500 Hz Blackman-gated tone bursts with a 2ms rise/fall and 0ms plateau presented at a rate of 5.1/second. Stimulus level was 125 dB pSPL. The bioelectrical activity was amplified and analog filtered (5 – 500 Hz) with a commercially produced neurophysiological amplifier (GN Otometrics, Tasstrup, Denmark). For each single record the electromyographic activity was digitized (at a rate of 5000 Hz) and recorded on a commercially available electrophysiological recording system (GN Otometrics, Tasstrup, Denmark). The recording epoch began 10 ms before the onset of the stimulus and continued for 40 ms after the stimulus and 80 single samples were collected during the block. Each cVEMP recording was repeated at least once to ensure reliability. Following signal averaging, the latencies of the prominent peaks were recorded as well as the peak- to-peak amplitudes and average RMS of the EMG.

cVEMPs were recorded from 3 different recording conditions, completed for both seating positions (See Table 1). Condition 1 was an open EMG condition that accepted all sweeps. The optimal activation (i.e. supine, head lifted, head turned) was used, but no EMG monitoring occurred and all sweeps were accepted. In condition 2, EMG monitoring occurred via the ChartrEP (i.e. clinician monitored) where a window was set in which a minimum amplitude value of 50 EMG and a maximum amplitude value of 300 EMG were required. Any sweeps in which the SCM EMG was below or above this cut-off were rejected and not included for signal averaging. During condition 3, we used the same EMG cut-off as condition 2 through the ChartrEP, except the subjects also held an EMG monitor during the test that they used as a visual

target. The EMG monitor indicated whether they were below or above the required, or whether they were within the target range EMG (as set by the tester using the ChartrEP). The conditions were randomized to prevent bias from muscle exertion. For conditions 1 and 2, the subjects will be instructed to turn and lift their head in the opposite direction of the side being tested. For condition 3, the subjects were given the same instructions in addition to having the monitor which they were instructed to keep the light green by turning their head. This indicates that the SCM is activated enough for a good reading.

In addition to the 3 recording conditions, amplitude normalization techniques were also used to calculate corrected amplitude from each of the 3 recording conditions. In this technique, the raw tonic EMG level, which was tabulated from each cVEMP recording, was used to normalize the cVEMP amplitude by dividing the EMG value into amplitude value of the final averaged cVEMP waveform.

Table 1: Test Conditions	
Condition	**Description**
1	Optimal activation only
2	Optimal activation + EMG monitoring through ChartrEP
3	Optimal activation + EMG monitoring through ChartrEP + visual target
Table 1: Description of the three recording conditions	

Results

Effects of recording condition on absolute cVEMP amplitude outcomes: EMG Monitoring

The mean cVEMP peak-to-peak amplitude and interaural amplitude asymmetry (IAA) values observed from all 3 conditions are shown in Table 2. A repeated measures ANOVA with a Greenhouse-Geisser correction determined that mean peak-to-peak absolute amplitudes were not statistically significantly different between the three recording conditions (Right Ear: $F_{(1.253, 12.527)} = 1.641$, $p = .229$; Left Ear: $F_{(1.597, 15.968)} = .33$, $p = .721$).

Table 2: Left and Right Amplitude and IAA Measures		
cVEMP Amplitude	Mean	Standard Deviation
Left C1 Amplitude	254.397	132.026
Left C2 Amplitude	237.351	103.145
Left C3 Amplitude	239.823	113.357
Right C1 Amplitude	260.408	113.211
Right C2 Amplitude	301.582	107.887
Right C3 Amplitude	283.012	109.309
C1 IAA	12.591	10.734
C2 IAA	16.123	17.407
C3 IAA	11.305	8.634
Table 2: The means and standard deviations for cVEMP amplitude from each ear and for each of the 3 recording conditions. Note: C1 = condition 1 C2 = condition 2 C3 = condition 3 IAA = interaural amplitude asymmetry		

Additionally, there were no statistically significant differences between recording conditions for interaural amplitude asymmetry ($F_{(1.572, 17.516)}=.489$, $p=.597$) and this is illustrated in Figure 3.

Figure 3: A bar graph showing the interaural amplitude asymmetry (percent difference in amplitude; left versus right). The thin black lines represent one standard deviation
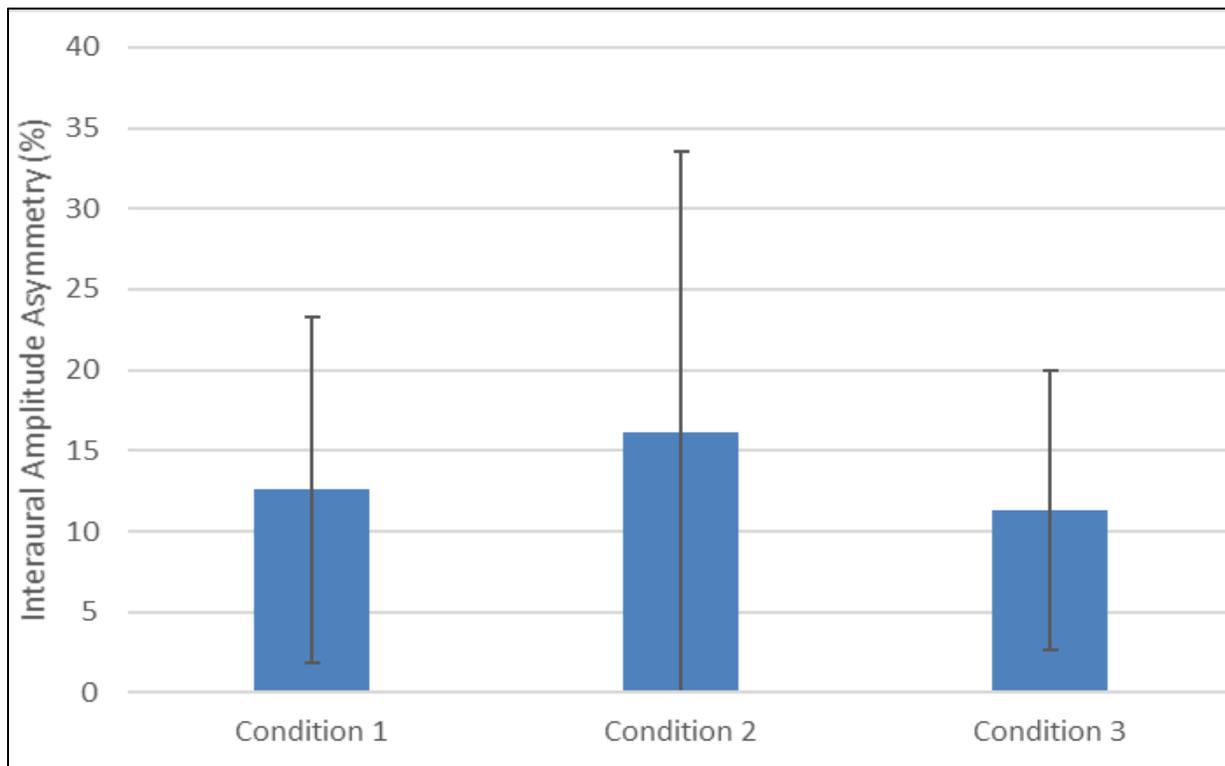

Figure 3: IAA Left vs. Right

The mean EMG generated from the SCM from each of the 3 conditions is shown in Figure 4. Although there was greater variability in the EMG during condition 1 (where no EMG monitoring occurred) shown by the large SD bars in Figure 4 (especially for the left ear), there were no statistically significant differences in EMG between conditions (Right ear: $F_{(1.632, 16.321)} = .327$, $p = .683$; Left ear: $F_{(1.022, 10.220)} = 1.469$, $p = .254$).

Figure 4: Bar graph showing the average EMG generated from each condition from both the right and left ears. The thin black bars represent 1 standard deviation
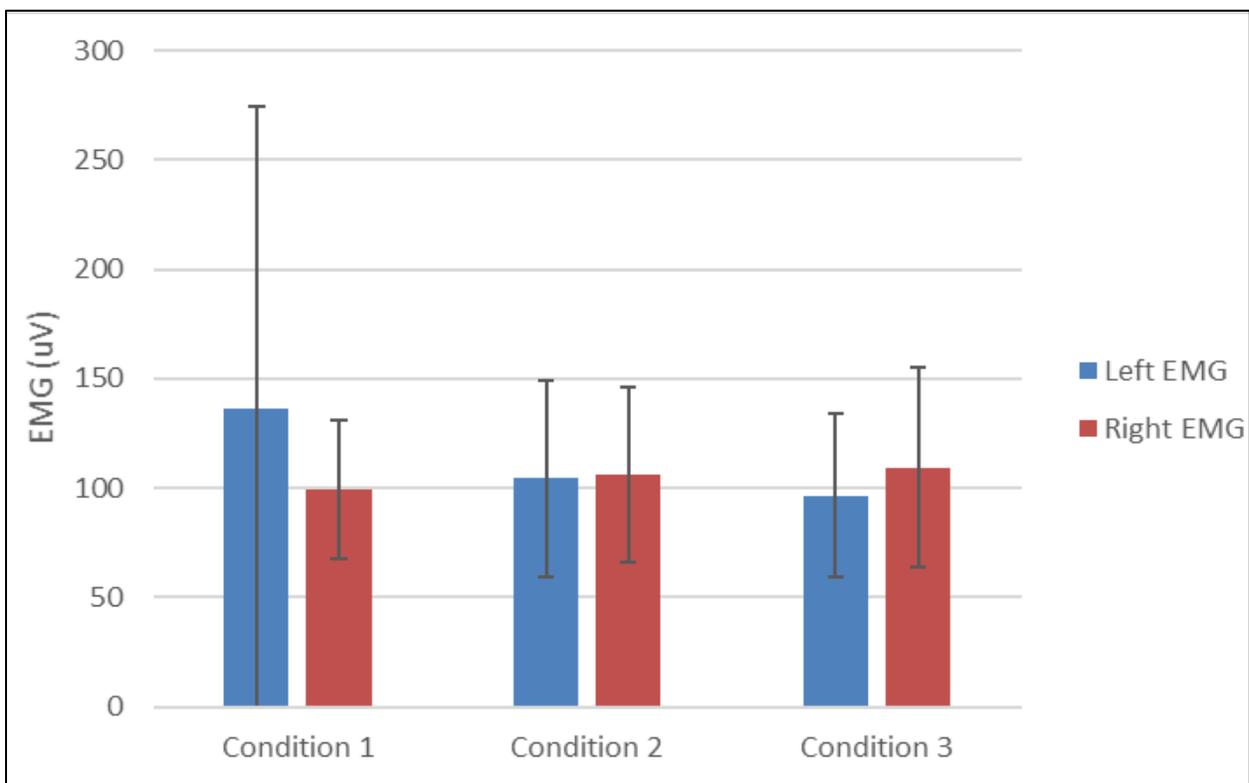

Figure 4: Average EMG

Effects of recording condition on corrected cVEMP amplitude (amplitude normalization)

The average EMG from each recording was divided into the amplitude to produce the corrected amplitude. This technique is called amplitude normalization, as amplitude values are "normalized" based on the EMG generated by the SCM. The corrected cVEMP peak-to-peak amplitude and interaural amplitude asymmetry (IAA) values observed from all 3 conditions are shown in Table 3.

Table 3: Corrected IAA Measures		
Corrected Amplitude and IAA	Mean	Standard Deviation
Left C1 Corrected Amplitude	2.225	0.696
Left C2 Corrected Amplitude	2.281	0.631
Left C3 Corrected Amplitude	2.456	0.617
Right C1 Corrected Amplitude	2.632	0.808
Right C2 Corrected Amplitude	2.862	0.629
Right C3 Corrected Amplitude	2.789	0.969
C1 IAA	12.635	15.194
C2 IAA	13.651	13.036
C3 IAA	14.565	11.573
Table 3: The means and standard deviations for cVEMP corrected amplitude for each ear and the interaural amplitude asymmetry for each condition with the left and right ear data averaged. Note: C1 IAA- Condition 1 Interaural Amplitude Asymmetry C2 IAA- Condition 2 Interaural Amplitude Asymmetry C3 IAA- Condition 3 Interaural Amplitude Asymmetry		

A repeated measures ANOVA with a Greenhouse-Geisser correction was conducted to determine whether the mean peak-to-peak normalized amplitudes that had been corrected based on EMG differed between recording conditions. Results show that there were no statistically significantly differences in normalized amplitude between the 3 recording conditions (Right ear: $F_{(1.837, 18.367)} = .439$, $p = .635$; Left ear: $F_{(1.870, 18.697)} = 1.399$, $p = .270$). Additionally, there were no statistically significant differences between recording conditions for corrected interaural amplitude asymmetry ($F_{(1.951, 19.515)} = .053$, $p = .823$) and the corrected IAA values from each condition are shown in Figure 5.

Figure 5: Bar graph showing IAA (percent difference in amplitude; left versus right) from each condition that has been corrected by using amplitude normalization. The thin black bars represent one standard deviation.
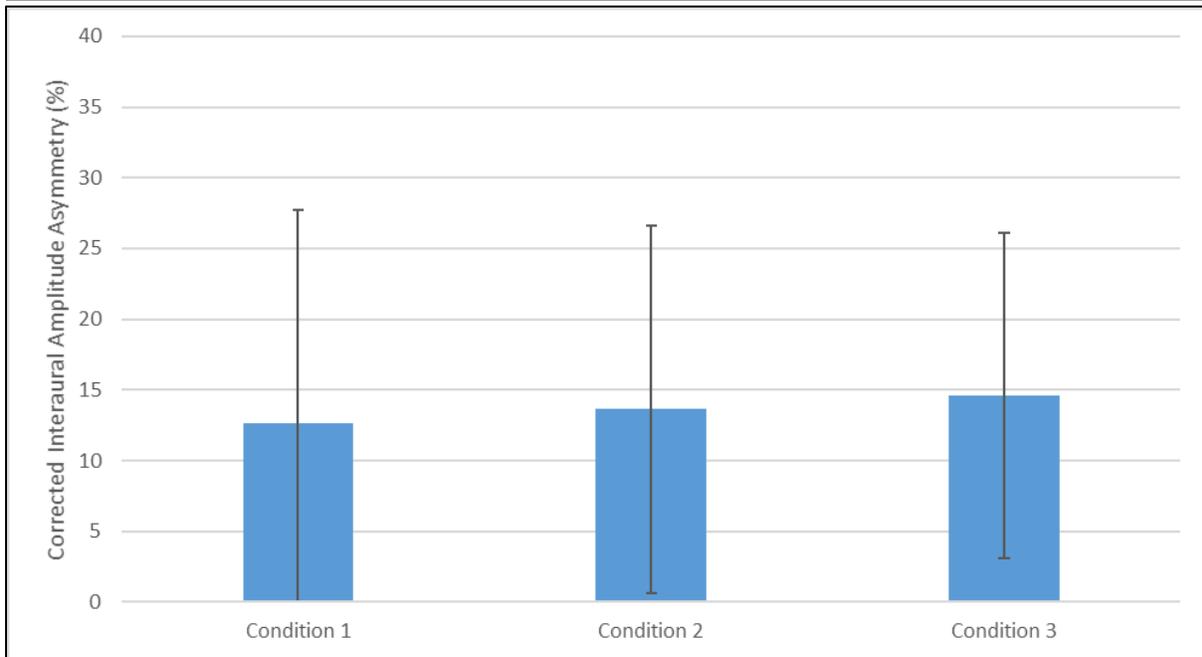

Figure 5: Corrected IAA

A repeated measures ANOVA with a Greenhouse-Geisser correction was conducted to determine whether there were differences in the calculated IAA between the six conditions where the conditions included the three recording conditions with their absolute values and the three recording conditions with their normalized and corrected values. There were no statistically significant differences in IAA calculations between the six conditions ($F_{(3.225, 32.251)}=.195$, $p=.910$).

Table 4 Effects of 6 Conditions on IAA		
Condition Type	Mean	Standard Deviation
Condition 1 IAA	12.59	10.73
Condition 1 IAA Corrected	12.63	15.19
Condition 2 IAA	16.12	17.41
Condition 2 IAA Corrected	13.65	13.04
Condition 3 IAA	11.31	8.63
Condition 3 IAA Corrected	14.56	11.57

Table 4: The mean and standard deviations of the conditions with the interaural amplitude asymmetry corrected and un-corrected data.

Note:
Condition 1 IAA- Condition 1 Interaural Amplitude Asymmetry
Condition 2 IAA- Condition 2 Interaural Amplitude Asymmetry
Condition 3 IAA- Condition 3 Interaural Amplitude Asymmetry

Control group data: Objective two

Table 5 shows the means and standard deviations for all cVEMP parameters, recorded from all 3 conditions, for both the supine and sitting positions, recorded from the 11 adult participants in the current study. The data set includes all amplitude parameters, both absolute and corrected, EMG, and latency values. There were no significant differences noted between the right and left ears, so the right and left ear data was combined to provide the means. For purposes of this thesis, no statistical comparisons are made as the data set will be used for a subsequent study (that is not part of this Honors Thesis) in which comparisons will be made between adult and pediatric cVEMP outcomes and the effect of EMG monitoring in a pediatric population compared to a young adult population.

Supine Position							
Test Condition	**Mean Amplitude**	**Mean EMG**	**Corrected Amplitude**	**IAA**	**Corrected IAA**	**Mean Latency**	**ILD**
Condition 1	266.89 (134.45)	131.81 (84.91)	2.20 (0.79)	14.78 (11.60)	14.96 (15.52)	14.86 (1.82)	0.64 (.57)
Condition 2	275.05 (145.09)	122.62 (51.66)	2.38 (0.94)	17.53 (15.78)	15.29 (13.04)	14.55 (1.56)	0.77 (.87)
Condition 3	248.04 (121.62)	108.41 (39.85)	2.44 (1.06)	11.06 (9.13)	14.45 (11.91)	14.61 (1.86)	0.85 (.84)
Sitting Position							
Test Condition	**Mean Amplitude**	**Mean EMG**	**Corrected Amplitude**	**IAA**	**Corrected IAA**	**Mean Latency**	**ILD**
Condition 1	155.27 (81.53)	87.15 (34.96)	1.89 (.70)	13.98 (11.98)	18.27 (14.32)	15.73 (2.43)	1.35 (1.58)
Condition 2	184.07 (71.91)	92.79 (22.57)	2.10 (.83)	14.59 (9.07)	14.90 (12.19)	15.90 (3.52)	.98 (.98)
Condition 3	176.19 (63.92)	79.09 (10.98)	2.31 (.75)	9.32 (5.79)	9.11 (6.59)	15.33 (2.23)	1.74 (3.15)

Discussion

Although the long-term goal is to assess the effects of EMG monitoring and amplitude normalization on the cVEMP recorded in a pediatric population, the first objective of this thesis was to replicate previous studies showing that EMG monitoring and amplitude normalization has no significant effect in young, healthy adults. Based on what we know and understand regarding the cVEMP and the direct effect EMG has on the response, it is counterintuitive to assume EMG monitoring has no significant effect on the cVEMP. However, several studies have shown this is in fact the case, at least for young healthy adult participants. For example, McCaslin et al. (2013) recorded cVEMPs from 97 healthy participants under 4 conditions: 1) no EMG monitoring, 2) EMG monitoring with a visual target, 3) no EMG monitoring but amplitude normalization was completed offline, and 4) EMG monitoring with a visual target and amplitude normalization. The mean age of the participants was 31 years. They designated a "pediatric" group that ranged in age from 5 – 17, and the mean age in that group was 10.81 years. They reported no significant differences in cVEMP amplitudes or in EMG activity between the recording conditions. They also stated that amplitude normalization "failed to reduce significantly the variability in the amplitude asymmetry data". Similarly, Tilburg et al. (2014) recorded cVEMPs from 20 healthy volunteers with a mean age of 29 years. They reported that amplitude normalization did not reduce the amplitude variability within-subjects. The current study used slightly different conditions (i.e. we had an additional condition of EMG monitoring without a visual target), but our findings are in agreement with both of these studies. That is, EMG monitoring and amplitude normalization did not significantly affect the cVEMP amplitude or amplitude asymmetry. We further analyzed the data to show that EMG monitoring did not significantly affect the raw EMG recorded from the SCM either.

The findings from the current study are encouraging and suggest that our testing set-up is consistent with others; however, it does not answer the question whether EMG monitoring and amplitude normalization are, or are not, critical aspects of cVEMP recordings in clinical populations. It only suggests that young, healthy adults can generate adequate, and equal, EMG from both their right and left SCMs. We do not yet know if this finding will be observed in older or younger populations, or in dizzy, clinical populations. The pediatric group from McCaslin et al. (2013) is arguably older than our target pediatric age. That is, their mean age was 10 years. A 10-year-old is, behaviorally, very different from a 2 to 4- year-old and can probably complete the cVEMP task in a similar manner as an adult. A young child, for whom the cVEMP is one of the few objective tests available, may not be able to do this task as easily. Behaviorally, a young child may struggle in the optimal supine position where they are required to lay down in the chair, turn and lift their head for about thirty seconds. Young children may not understand the task or may be nervous and wiggly. This will result in EMG variability and if they are unable to turn their head equally on both sides will result in an amplitude asymmetry suggestive of a vestibular disorder. Fortunately, amplitude normalization is known to correct for asymmetrical EMG. For example, McCaslin (2014) had participants intentionally produce asymmetrical EMG from the right and left sides. They successfully showed that amplitude normalization was able to adequately correct for intentional EMG asymmetries and produce symmetrical cVEMP responses.

In addition to successfully replicating previous studies, we ran an additional condition in which EMG monitoring was completed using an EMG window on the Chartr EP both with and without a visual monitor. Previous studies only used the visual condition and were not able to make a comparison between EMG monitoring with or without the visual target. The visual

monitor provided a form of biofeedback for the participants and allowed them to adjust their SCM contraction accordingly. Anecdotally, the participants commented on how it was easier for them to adjust their head in the condition with the visual target. Additionally, the test time was slightly quicker with the visual target because the test did not have to run as many sweeps. That is, there were less rejections and more accepts so test time was reduced. However, no major differences were observed in the final cVEMP response. It may be that the use of the visual monitor provides some comfort to participants, even if it does not affect their cVEMP recording. This finding is helpful for future pediatric studies in which the child is not able to attend to the visual target. If they can attend to the target, it may make the task easier. If they cannot, EMG monitoring without the visual target should be adequate.

The two seating positions, supine and sitting upright, were used for our second objective to create a future control group. Although the supine position is considered the optimal position for the cVEMP test and yields larger EMG values and subsequently larger cVEMP amplitudes, the cVEMP can also be recorded in the sitting position for most participants. It should be noted that all of the participants were able to generate enough EMG ($50\mu V$) when in the supine position. However, while in the sitting position, two of the participants were not able to generate enough EMG to be within the test condition parameters and their cVEMP was absent when sitting upright. This finding further supports the use of EMG monitoring in children. Several pediatric clinics who routinely conduct cVEMP testing in young children recommend having the child sit in the parent's lap (Alfred I. DuPont Hospital, O-Reilly et al. 2013; Boys Town National Research Hospital; Rodriguez, personal communication). In cases where the child is sitting in their care-givers lap and the cVEMP is absent, it may be due to inadequate EMG. For this reason, it is very important we monitor EMG.

References

Akin, F. W., Murnane, O. D., Panus, P. C., Caruthers, S. K., Wilkinson, A. E., & Proffitt, T. M. (2004). The influence of voluntary tonic EMG level on the vestibular-evoked myogenic potential. *The Journal of Rehabilitation Research and Development,41*(3b), 473. doi:10.1682/jrrd.2003.04.0060

Curthoys IS. A critical review of the neurophysiological evidence underlying clinical vestibular testing using sound, vibration and galvanic stimuli. Clin Neurophysiol. 2010;121(2):132–144.

Data and Statistics. (2017, March 22). Retrieved April 06, 2017, from https://www.cdc.gov/ncbddd/hearingloss/data.html

Jacobson, G. P., & Shepard, N. T. (2016). *Balance function assessment and management*. San Diego, CA: Plural Publishing.

Mccaslin, D. L., Jacobson, G. P., Hatton, K., Fowler, A. P., & Delong, A. P. (2013). The Effects of Amplitude Normalization and EMG Targets on cVEMP Interaural Amplitude Asymmetry. *Ear and Hearing,34*(4), 482-490. doi:10.1097/aud.0b013e31827ad792

Mccaslin, D. L., Fowler, A., & Jacobson, G. P. (2014). Amplitude Normalization Reduces Cervical Vestibular Evoked Myogenic Potential (cVEMP) Amplitude Asymmetries in Normal Subjects: Proof of Concept. *Journal of the American Academy of Audiology,25*(3), 268-277. doi:10.3766/jaaa.25.3.6

Nicolini-Panisson, R. D. and Donadio, M. V. F. (2014), Normative values for the Timed 'Up and Go' test in children and adolescents and validation for individuals with Down syndrome. Dev Med Child Neurol, 56: 490–497. doi:10.1111/dmcn.12290

O'Reilly, R., Morlet, T., & Cushing, S. L. (2013). *Manual of pediatric balance disorders*. San Diego: Plural Pub.

Outlander Academy. (n.d.). Anatomy Lesson #11: Muscles of Facial Expression. Retrieved April 03, 2017, from http://www.outlanderanatomy.com/jamies-face-or-ye-do-it-face-to-face//

Rosengren, S. (2015). Effects of muscle contraction on cervical vestibular evoked myogenic potentials in normal subjects. *Clinical Neurophysiology,* 126(11)

Piker, E. G., Jacobson, G. P., Burkard, R. F., Mccaslin, D. L., & Hood, L. J. (2013). Effects of Age on the Tuning of the cVEMP and oVEMP. *Ear and Hearing,34*(6). doi:10.1097/aud.0b013e31828fc9f2

Tilburg, van M., Herrmann, B., Guinan, J. and Rauch, S. (2014). Normalization Reduces Intersubject Variability in Cervical Vestibular Evoked Myogenic Potentials. *Otology & Neurotology*, 35(8), pp.e222-e227.

Valente, M. & McCaslin, D.L. (2011). Vestibular Disorders and Evaluation of the Pediatric Patient. *The ASHA Leader,* 16(3), 12-15. Doi: 10.1044/leader.FTR2.16032011.12.