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Cervical vestibular-evoked myogenic potentials (cVEMPs): "Differentiation of inter-neck EMG symmetry between children and adults"

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Cervical Vestibular-Evoked Myogenic Potentials (cVEMPs):

"Differentiation of Inter-Neck EMG Symmetry Between Children and Adults"

An Honors College Project Presented to

the faculty of the Undergraduate

College of Health and Behavioral Sciences

James Madison University

by Ellen Marie Jones

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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.

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This work is accepted for presentation, in part or in full, at the Honors Symposium on April 5th, 2019

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Acknowledgments

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Abstract

A cervical Vestibular-Evoked Myogenic Potential (cVEMP) is one of the few objective vestibular diagnostic tests available for pediatric populations. This test evaluates the functionality of the saccule end organ through an inhibitory reflex on the sternocleidomastoid (SCM) muscle that inhibits the level of electromyographic (EMG) activity (Wiener-Vacher, 2013). Because the saccule response is measured as an inhibition of EMG in the SCM, it is imperative that the SCM have a tonic contraction prior to eliciting the response and that the contraction of the SCM is equal on the right and left sides. It is generally accepted that young, healthy adults can generate equal amounts of EMG on both their right and left sides, but these results have not been replicated in young children. There is very little cVEMP data for children under five years of age, and EMG, EMG monitoring, and amplitude normalization has not been studied in this age group. As a result, this study sought to compare generated EMG levels between pediatric and adult populations, to determine if EMG monitoring and amplitude normalization would significantly reduce interaural amplitude asymmetry (IAA) in either group, and to assess any developmental effects on cVEMP parameters. During testing, participants were placed in a seated, head-turned, position. An iPad was used to incentivize children to turn their head for a better SCM muscle contraction; adults were simply asked to turn their heads. Our findings showed that children were able to produce similar EMG values as adults in the same position, and that they were able to generate equal amounts of EMG on both their right and left sides. While we did not find statistical evidence for the use of EMG monitoring and amplitude normalization when performing a cVEMP, there were individual cases within our data that showed using these techniques could have clinical relevance.

Introduction

History and Significance of Vestibular-Evoked Myogenic Potentials (VEMPs)

In 1929, Pietro Tullio began studying the vestibular system and how sensitive it is to auditory stimuli. Tullio created perforations in the labyrinth of pigeons and watched what the motion of the labyrinth fluids looked like when he played sound though a flute. The frequency of the notes played on the flute were matched by the frequency of the movement of the endolymph. Through this observation, Tullio was able to discover that the vestibular system can be stimulated using sound (Tullio, P., 1929). This finding intrigued and paved the way for many researchers to look closer into the abilities of the vestibular system.

Von Békésy in 1935 found that high frequency sounds presented to an ear result in head displacement toward that stimulated ear. Because of Von Békésy's observations, he was able to conclude that the head response to the stimuli was due to endolymph stimulating the vestibular system (Von Békésy, G., 1935). In 1964, Bickford, Jacobson, and Cody found that the presence of a sound-evoked electrical potential could be recorded by placing an active electrode on the projecting part of the occipital lobe, or the inion. Through this discovery, they were able to determine that this phenomenon is not neurogenic in nature and that the response grew in amplitude when the tonic level of EMG in the neck extensors was increased (Bickford, Jacobson, & Cody, 1964). These researchers later coined the term "inion potential" to describe this evoked response. The vestibular system in considered to be a peripheral origin to this inion potential (Bickford, Jacobson, & Cody, 1964). The inion potential is a term that is still commonly referenced to this day when discussing vestibular functioning.

Cervical Vestibular-Evoked Myogenic Potentials were discovered in 1992 when James Colebatch and Gabor Halmagyi found another short-latency and large amplitude myogenic potential that is elicited with a loud click and recorded with an electrode placed on a contracted sternocleidomastoid (SCM) muscle. This potential is characterized by a positive (P1) and negative (N1) wave occurring on the same side as the ear that received the stimulus (Colebatch & Halmagyi, 1992). This test evaluates the functionality of the saccule end organ through an inhibitory reflex on the SCM that alters the level of electromyographic (EMG) activity. EMG is measured from the contracted sternocleidomastoid (SCM) muscle that corresponds to the same side as the ear that is being stimulated (Wiener-Vacher, 2013). The loud click or tone burst stimuli may be delivered through either air conduction or bone conduction pathways. High-intensity, low-frequency, acoustical transient is presented through the ear canal and the sound pressure is routed through the middle ear system to the oval window, which leads into the vestibule (Lysakowski et al., 1998). While this is happening, endolymph in the vestibule is moved and the hair cells (type I and II) are sheared resulting in transduction. The patient does not have to be able to hear to evoke the stimulus, but the middle ear mechanisms must be intact if using an air-conducted stimulus. In the early two thousand’s, VEMP testing became an integral part of the test battery that is used on many patients evaluated for dizziness and vestibular loss.

The cVEMP Pathway

The cVEMP pathway is characterized by a saccullo-collic response that comes from a reflexive adjustment of the musculature in the neck that is triggered by activation in the saccule (McCaslin & Jacobson, 2008). This reflex consists of an afferent (activation) limb, central processing, and an efferent (termination) limb. The afferent limb pathway extends from the saccule to Scarpa's ganglion where neural projections course through the inferior branch of the vestibular nerve (McCue & Guinan, 1995; Murofushi & Curthoys, 1997). Because of this, the inferior vestibular nerve becomes part of the VIIIth cranial nerve and the fibers projecting from the saccule terminate on the interneurons.

On the other hand, the efferent limb pathway descends from the vestibular nucleus and courses through the vestibulo-spinal tract to the motor nucleus of CNXI, the Accessory Nerve. In response to this, activity is then routed through CNXI to terminate on the sternocleidomastoid muscle (Fitzgerald, Comerfiord, & Tuffery, 1982).

Amplitude and Amplitude Asymmetry

Amplitude represents an interaction between tonic EMG level and the size of the inhibitory postsynaptic potential (IPSP) initiated at the end organ (Colebatch & Rothwell, 2004). Maximum cVEMP amplitude is obtained by using short-duration, low-frequency tone bursts. In addition, the level of the stimulus used to elicit a cVEMP response directly influences the amplitude of the cVEMP (McCaslin & Jacobson, 2008). When recording a cVEMP, it is necessary to have a high-intensity stimulus with a short onset time. Stimulus intensities around 75 dB HL or below are not sufficient to generate a cVEMP in most individuals who have normal vestibular function, and therefore these intensities should not be used (Akin et al. 2003; Papathanasiou, Murofushi, Akin, & Colebatch, 2014). Another suggestion that McCaslin and Jacobson make when recording cVEMPs is to keep the stimulus repetition rate around 5 Hz. By doing so, the amplitude and reproducibility will be maximized to their greatest extent (McCaslin & Jacobson, 2008). In other words, as the stimulus rate is increased and stretched further away from 5 Hz, the cVEMP peak-to-peak amplitude has been shown to decrease significantly as a result.

Lastly, when performing VEMP testing, it is essential that the participant's neck is positioned in a stable and contracted position so that an accurate measurement can be achieved (Wiener-Vacher, 2013). If the level of tonic activity is not sufficiently achieved through SCM contraction, then the amplitude of the VEMP will be relatively small because of the lack of contraction.

Latency

Cervical VEMPs are characterized by their biphasic waveforms that begin with a positive wave followed by a negative wave. The positive wave occurs at about 13ms and is called P1, while the negative wave occurs at about 23ms and is referred to as N1 (Colebatch & Halmagyi, 1992).

Pediatric cVEMPs

VEMP amplitude and threshold vary with the age of the individual. Specifically, VEMP amplitudes are significantly smaller in elderly adults and are reportedly greater for children between the ages of 6 months and 12 years of age, compared to young adults (Wiener-Vacher, 2013). After 12 years of age, VEMP thresholds begin to increase as the individual ages (Wiener-Vacher, 2013). VEMP latencies tend to remain relatively stable over the lifespan. Wiener-Vacher (2013) also states that EMG levels recorded from the SCM tend to decrease in older adults, but it is not known whether EMG levels are different between children and young adults. Further, it is not known if EMG monitoring or amplitude normalization (based on the EMG) are more or less effective in pediatric populations compared to adults.

In older children and adults, it is common practice to use visual feedback of EMG levels to help the patients achieve appropriate neck-muscle contraction. Wiener-Vacher (2013) reported that the use of EMG targets in young children is impossible and that it is, instead, the responsibility of the technician to monitor and adjust the child's EMG levels/muscle contractions to ensure proper results during testing sessions. When trying to evaluate the best way to position a child under the age of six for VEMP testing, it is likely best to seat the child on their parent's lap and have them sit face to face to one another (Wiener-Vacher, 2013). It is then the responsibility of the parent to slightly tilt the trunk of their child backwards so that the child must effortfully straighten themselves up to look or play with a provided toy (Wiener-Vacher, 2013). When the child reaches for the toy, a more efficient sternocleidomastoid muscle contraction is achieved, which leads to better EMG levels and data for the specific pediatric patient. Even when playing with a desired toy, it is likely that young children may become tired or uncooperative. When a child becomes tired or uncooperative, their neck-muscle contractions may begin to have irregular amplitudes (Wiener-Vacher, 2013). It is for this reason that small breaks or changes in attention are essential during testing to ensure the best results possible for young patients.

EMG Monitoring and Amplitude Normalization

One of the most diagnostically useful parameters of the VEMP for assessing vestibular function is the response amplitude. However, the amplitude of the VEMP is also directly related to the level of tonic EMG generated by the SCM (Akin et al., 2004). It is essential to monitor EMG and understand the causes of its variability to ensure that audio-vestibular and neurological disorders are not present in an individual. VEMPs, therefore, allow for researchers to analyze the saccular and/ or vestibular nerve function to get a better understanding of potential pathologies or abnormalities (Akin, et al., 2004). It is not uncommon for patients to be unable to create equal amounts of EMG for testing the left and right side of the head; therefore, taking note of the levels of sternocleidomastoid activation is essential in receiving accurate and reliable interaural measures. The two main ways of controlling tonic EMG in a patient is through visual feedback and amplitude normalization.

When looking at patient self-monitoring, it incorporates the use of biofeedback to allow for patients to look at a visual target that represents EMG amounts during their EMG recordings. The target allows for the patient to look at their own EMG levels and compare it to what the target EMG window looks like. After looking at the EMG target window, the patient can try to increase, decrease, or maintain their EMG levels to fall within the accepted target range of values. If a given patient’s EMG goes too high or too low from the target window, their EMG values, or 'sweeps,' are rejected. Before an EMG target window can be created, the variability of EMG must be determined for a patient. A study by McCaslin and colleagues on how to determine an EMG target window showed that "as the EMG target increases, background muscle activity variability increases, and the window should be widened (McCaslin & Jacobson, 2008)." Due to the corresponding increase in EMG when cVEMP amplitude is increased, it is essential that level of EMG is always recorded during cVEMP testing. It is also important to note, after closely studying the impact of the VEMP amplitude on background muscle activity, researchers determined that minimum EMG levels should fall somewhere between 30 and 50 microvolts when recording a cVEMP (McCaslin & Jacobson, 2008).

cVEMP amplitude normalization is the second way that asymmetrical tonic EMG can be controlled during cVEMP recordings. Amplitude normalization involves using a mathematical correction to account for asymmetrical EMG. This process involves "collecting a sample of tonic EMG activity preceding the stimulus onset during each recording epoch and then calculating the mean RMS value of the rectified pre-stimulus EMG to derive an average (Colebatch, Halmagyi,

& Skuse, 1994)." Various studies in the past years have verified the importance of using either EMG self-monitoring or amplitude normalization formulas to account for variation in cVEMP amplitudes within subjects (i.e. between an individual's right and left side).

Although EMG monitoring and amplitude normalization are effective techniques for controlling asymmetrical EMG activation, recent studies suggest these techniques may not be needed in young adults. McCaslin et al. (2013) examined both of these methods in a sample of 97 healthy subjects. There were four conditions that the cVEMP was recorded in. (1) having the participant sit semirecumbent with their head turned elevated and away from the stimulated ear (EMG monitoring or amplitude normalization was not used), (2) The same as condition 1 but included the use of a visual target that was set at a minimum of 50 µV for the subject to reference, (3) The same as condition 1 but included the use of amplitude normalization for the EMG levels, and (4) The same as condition 1 but included the use of both a visual target that was set at a minimum of 50 µV AND the use of amplitude normalization. They found no significant differences in cVEMP amplitude asymmetry between the conditions. They concluded that the optimal recording position, semirecumbent with the head turned and elevated, was sufficient to generate equal EMG from the right and left without the use of monitoring.

Although EMG monitoring and amplitude normalization may not be needed in young adults, it is not known whether these techniques produce more reliable and accurate VEMP results in young children. Additionally, differences in EMG between adults and children has not been studied, and young children may not be able to complete the task in the "optimal recording position" of laying supine with the head turned and lifted. In fact, clinicians experienced with vestibular testing in young children recommend sitting the child on their caregiver's lap and simply turning their head. It is important to know if this technique produces adequate EMG, and whether using EMG monitoring or amplitude normalization is effective using this technique.

Objectives and Hypothesis

The objectives of this study were to (1) measure the level of EMG generated and inter-neck EMG symmetry in a cohort of young children (2-5) compared to a cohort of young adults in the sitting, head turned, position, (2) to assess any developmental effects on cVEMP parameters including latency, amplitude, and interaural values, and (3) to determine whether EMG monitoring and amplitude normalization are effective in reducing cVEMP interaural asymmetry values in pediatric populations and young, healthy adults in a sitting position. It was my hypothesis that inter-neck EMG symmetry would be more consistent in adult participants when compared to pediatric participants because young children may find it difficult to sit still and complete the task. Based on previous studies comparing pediatric groups (i.e. mean age ~10, older than our cohort) to adults, I hypothesized that the pediatric group would show larger cVEMP amplitudes and longer latencies. Further, it was my hypothesis that applying EMG monitoring and amplitude normalization techniques would reduce cVEMP amplitude asymmetry significantly in pediatric participants due to difficulty maintaining the head position for the task yielding possible EMG asymmetries from the right and left side of the neck. Based on previous studies, I hypothesized that there would be no significant effect of amplitude normalization on the amplitude asymmetry in the adult group.

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Participants

This investigation was approved by the Institutional Review Board of James Madison University. Full informed consent was obtained from each participant.

The participants of this study were split into two age groups: pediatrics and young adults (**Table I**). For the pediatric age group, the majority of the participants were recruited by sending a mass email to all James Madison University faculty and staff. Some participants were recruited by word-of-mouth through the assistance of my Honors Capstone Advisor, Dr. Erin G. Piker.

For the adult age group, I used previously collected data from Kim Fleck's Honors Capstone Project that she analyzed during her time at James Madison University. Kim Fleck's Honors Capstone Project focused on the impact of using EMG monitoring in cVEMP testing with young, healthy adults (Fleck, 2018).

In the pediatric age group, there were 7 children tested with a mean age of 3.71 (±.756) years. Two additional pediatric participants were consented but could not complete the testing and are not included in the analysis. In the adult age group, there were 17 participants with a mean age of 20.59 (± .795) years. Prior to conducting the cVEMP testing, each participant had otoscopy and tympanometry performed on them to ensure that they did not have any middle ear issues that would alter the results of our test.

Age Group	Sex	Age Range	Mean Age
Pediatric (n=7)	3 males	2 to 5	3.71 (± .756)
	4 females		
Adult (n=17)	2 males	20 to 23	20.59 (± .795)
	15 females		

Table I: Demographics of study participants

Methodology

Pediatric participants were placed on their parent's lap or sat upright in a chair alone. Disposable silver/silver-chloride electrodes were used. The non-inverting input of the cVEMP was placed on the sternocleidomastoid muscle (SCM) midway between the insertion at the mastoid and the sternum ipsilateral to the side of stimulus presentation (**Figure I**). The inverting electrode was placed on the sternum. The ground electrode was placed at Fpz. Individual electrode impedances were ≤ 10 kOhms and interelectrode impedances were ≤ 5 kOhms. Ongoing EMG in the SCM was monitored using a second surface electrode placed on the SCM, directly below the non-inverting electrode, to measure the tonic background EMG activity (Akin et al. 2004).

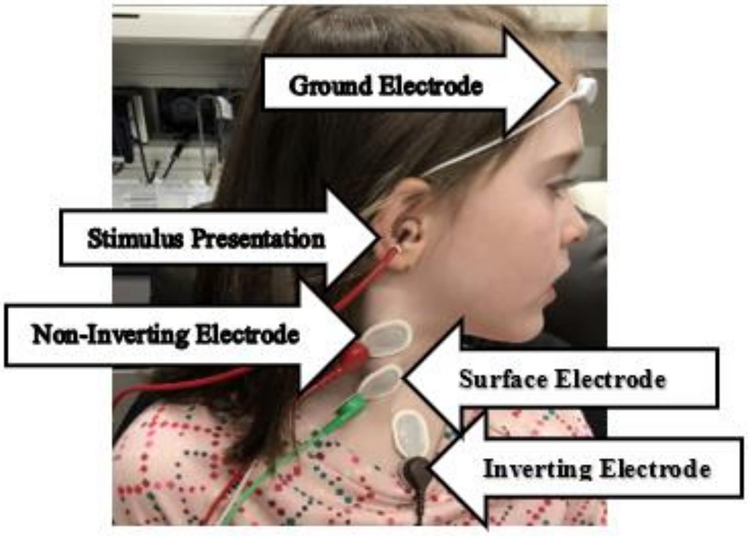

Figure I: Electrode Placements

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. **Figure II** shows the characteristics of a typical cVEMP waveform for the right and left ear. The positive P1 and negative N1 waves illustrate the biphasic nature of a cVEMP waveform. Amplitude is a measure from the peak of P1 to the peak of N1 and latency measures the number of milliseconds between these two peaks.

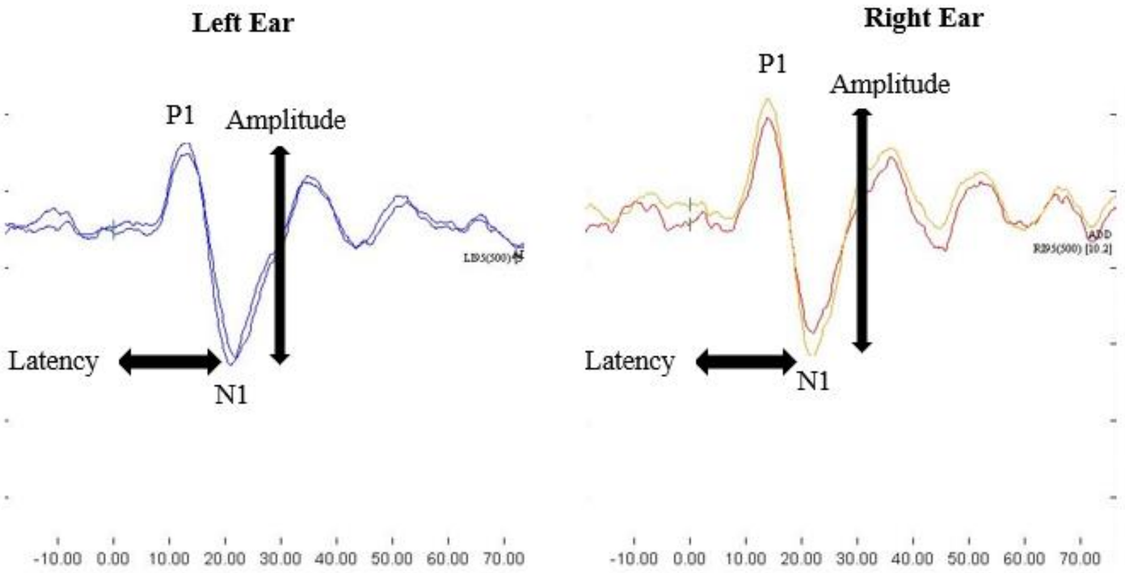

Figure II: cVEMP waveform illustrating the peak-to-peak amplitude and latency values for a healthy child's right and left ear

To record the cVEMP, the child sat upright and turned their head to the contralateral side of the SCM we were seeking to contract. An iPad was used to incentivize the child to turn their head (**Figure III**). When the iPad was positioned on the contralateral side of the elicited stimulus, a more efficient SCM muscle contraction was achieved, leading to better EMG levels and data for the participant. The parent and I worked to maintain that position long enough to acquire 80 samples at a rate of 5/second. Participants were given rest periods as needed. All recordings were replicated a minimum of one time so that repeatability of the data could be assessed. The adult group was tested in the exact same position, but without the iPad.

Figure III: Example of an iPad being used to incentivize a child to turn their head. Stimulus is presented to the right ear, child turns their head to the left to contract the right SCM.

Results

Data Reduction

An initial analysis was completed to determine whether there were ear effects (i.e. right or left ear) on the cVEMP amplitude, EMG, or corrected amplitude. A series of paired sample t-tests were completed, and results showed no significant effect of ear ($p > 0.05$). As such, data from the right ear only was used for all subsequent analyses unless the outcome variable was a measure of interaural amplitude asymmetry (IAA) or interaural latency difference (ILD), in which data from both the right and left ears were used.

Age and cVEMP Latency

The mean cVEMP latency and ILD values for the pediatric and adult participant groups are shown in **Table II**. An independent sample t-test was conducted to determine whether subject age (pediatric vs. young adult group) had a significant effect on the dependent variables of cVEMP latency and interaural latency difference (ILD). Although the adult group had slightly greater cVEMP latency values compared to the pediatric group (15.68 ms versus 14.36 ms, respectively), the differences were not significant ($t = 1.55$, df = 14.42, $p = .143$). Additionally, the pediatric group had higher ILD values when compared to the adult group (2.0 ms versus 1.06 ms, respectively), but the differences were not significant ($t=-1.92$, df= 10.06, $p= .084$).

Age Group	Latency (ms)	ILD
Pediatric	14.36 (1.73)	2.0 (1.13)
Adult	15.68 (2.18)	1.06 (.97)

Table II: Mean cVEMP latency and ILD

Age and cVEMP Amplitude

The mean cVEMP peak-to-peak amplitude, corrected amplitude, EMG, IAA, and corrected IAA values for the pediatric and adult participant groups are recorded in **Table III**. An independent sample t-test was conducted to determine whether subject age (pediatric vs. young adult group) had a significant effect on the dependent variables. Although the adult group produced larger cVEMP amplitudes compared to the pediatric group (159.03 µV versus 103.29 µV, respectively), the differences were not significant (*t* = 1.917, df = 22, p = .068). No significant group differences were observed for IAA (*t* = -1.995, df = 22, p = .059) or corrected IAA (*t* = -1.898, df = 22, p = .072).

Age and EMG

Figure II shows individual mean cVEMP peak-to-peak amplitudes as a function of EMG. For all participants (both adult and pediatric groups). There is a linear relationship between EMG and amplitude in this study cohort, consistent with the literature. As shown in **Figure II**, a participant who produced large amounts of EMG had large cVEMP amplitudes. Furthermore, a participant who produced small amounts of EMG had small cVEMP amplitudes.

The mean EMG generated was very similar between the two age groups (Table III). There was no significant difference in EMG between groups (*t* = .198, df = 2, p = .845). We also examined EMG asymmetry between groups. That is, the percentage difference in EMG between the right and left ears as this could have an effect on cVEMP amplitude asymmetry. The average EMG asymmetry between ears for the adult group was 17.01% (SD 14.9). The average for the pediatric group was 22.2% (SD 8.7). Comparisons of EMG asymmetry between groups were not significant (*t* = -.855, df = 22, p = .402).

Age Group	Amplitude	Corrected Amplitude	EMG	IAA	Corrected IAA
Pediatric	103.29 (41.07)	1.25 (.58)	89.43 (34.33)	16.69 (15.80)	17.80 (11.0)
Adult	159.03 (71.65)	1.82 (.71)	92.71 (37.83)	12.80 (11.35)	15.40 (9.06)

Table III: The means and standard deviations for cVEMP amplitude, EMG, IAA, and corrected IAA

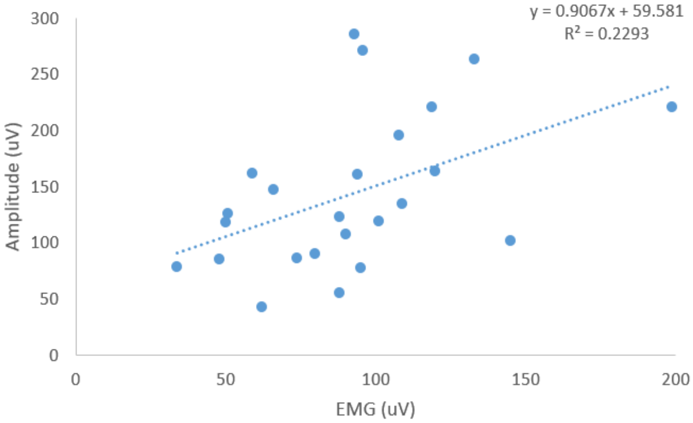

Figure IV: Data from all adult and pediatric participants showing cVEMP amplitude as a function of EMG

Clinical Utility of EMG Monitoring and Amplitude Normalization

In a typical clinic or lab, a cut-off value for the cVEMP IAA is calculated as the mean ± two standard deviations (SD) from the mean. An IAA value greater than +2 SD from the mean would be considered abnormally asymmetrical. **Table IV** shows the mean uncorrected interaural amplitude asymmetry, corrected interaural amplitude asymmetry, and interaural latency differences, and their respective cut-off values.

While correcting for EMG only marginally changed the IAA cut-off value for the adult group (i.e. 35% to 33%), it did lower the cut-off value for the pediatric group (i.e. 48% to 39%). This is important clinically.

An examination of individual participants shows the clinical utility, and need, for monitoring EMG in both pediatric and adult age groups (**Table V**). Adult group subject number CVKF17 in our data set showed that correcting for EMG changed the IAA from 45% (abnormal in some clinics) to 19% (well within normal limits). Furthermore, pediatric group subject number PCV7 in our data set showed that correcting for EMG changed the IAA from 67% down to 39%. In these cases, a patient's test results may be interpreted as abnormal indicating an impairment of the saccule on one side, when in fact the vestibular system is normal. The EMG asymmetry resulted in a cVEMP amplitude asymmetry.

Conversely, there are examples where correcting for EMG increased the IAA, putting it in, or close to, an abnormal range. Adult group subject number CVKF16 in our data set showed that correcting EMG changed the IAA from 12% up to 40%. Additionally, pediatric group subject number PCV6 in our data set showed that correcting for EMG changed the IAA from 30% to

50% (abnormal in many clinics). In these examples, the patient's initial results may have been interpreted as normal when in fact there may be a significant vestibular asymmetry

Age Group	Uncorrected Asymmetry (%)	Uncorrected Cut-off	Corrected Asymmetry (%)	Corrected Cut-off	ILD Cut-off
Pediatric	16.69	48.2	17.8	39.8	4.2
Adult	12.7	35.3	15.3	33.4	3.0

Table IV: Mean interaural amplitude asymmetry and interaural latency differences and cut-off values, wherein the cut-off is designated by the mean + 2 SD

Group Subject Number	Uncorrected IAA	Corrected IAA
CVKF17	45%	19%
PCV7	67%	39%
CVKF16	12%	40%
PCV6	30%	50%

Table V: Comparisons of uncorrected IAA and corrected IAA between adult and pediatric participants

Discussion

Adults versus Pediatrics

Very little cVEMP data exists for children under five years of age and EMG, EMG monitoring, and amplitude normalization has not been studied in this age group. In a comfortable, seated position with their head turned, children were able to produce similar EMG values as adults in the same position. Further, the EMG was symmetrical between the right and left and children were successfully able to maintain EMG for the duration of the cVEMP recording. Overall, the cVEMP findings of the pediatric group were very similar to the findings of the adult group.

When looking at the impact of age on cVEMP latency, amplitude, and EMG, I hypothesized that the pediatric group would show larger cVEMP amplitudes and longer latencies than the adult group. Further, it was my hypothesis that inter-neck EMG symmetry would be more consistent in adult participants when compared to pediatric participants, and that applying EMG monitoring and amplitude normalization techniques would reduce cVEMP amplitude asymmetry significantly in pediatric participants. The results of our study found differences between the pediatric and adult participant groups to be non-significant for all values.

After conducting a literature review, I was able to locate five previous studies that compared pediatric cVEMP data with adult cVEMP data. All five of these studies had a mean pediatric participant age of 6.5 years or older, while our study had a mean participant age of 3.7. That is, most pediatric cVEMP studies examine elementary school age children, who are old enough to complete several other objective vestibular assessments. Studies rarely assess preschool-aged children and younger who may be more difficult to test and for whom the VEMP is one of the few objective vestibular diagnostic tests available. Additionally, while all five studies mentioned EMG monitoring in their methodologies, only two reported and discussed EMG in their results sections. As a result, there is relatively no EMG data for us to compare our pediatric subjects to.

Picciotti, et al. (2006) split their pediatric participants into two age groups: "pre-scholar" (ages 3-5) and "scholar" (ages 6-15). This study also had an adult control group with a mean age of 32.17. Participants laid supine on a bed and were instructed to raise their head in order to bilaterally activate their neck flexors. Similar to our findings, Picciotti, et al. (2006) found that there were no significant differences between the pre-scholar and adult control group in cVEMP peak latencies. The pre-scholar group had a mean P1 latency of 16.13 ms, while the control adult group had a mean P1 latency of 15.92 ms. Our pediatric group had a similar mean P1 latency of 14.36 ms, and our young adult group had a mean P1 latency of 15.68 ms. Although participant testing position differed between our two studies, the age range of the pre-scholar participant group (ages 3-5) most closely resembled the age range of the pediatric participant group used in our study (ages 2-5). The similarities in age among pediatric participants may be why the results of our studies were in agreement. EMG was monitored in this study, but details regarding how EMG was monitored were not reported, the EMG values were not reported, and amplitude normalization was not performed.

Hsu, Wang, & Young (2009) ran 15 healthy children with a mean age of 7, and 15 healthy adults with a mean age of 27. The results of this study found that there was a significant difference in cVEMP latency for the first positive peak (P1) between children and adults. This study showed that as a child grew in age, height, and body weight, their P1 latency increased. The child group in this study had a mean P1 latency of 13.8 ms, while the adult group had a mean P1 latency of 14.6 ms. This is very similar to the mean P1 latencies found in our data for the pediatric (14.36 ms) and young adult (15.68 ms) groups. It is possible that variations in statistical methods and larger sample size led to the Hsu, Wang, & Young (2009) study finding P1 latency differences between children and adults to be significant when our study did not. However, similar to our results, this study found peak-to-peak amplitude differences between children and adults to be non-significant. The child group in this study had a mean peak-to-peak amplitude value of 122 µV and the adult group showed a similar mean amplitude of 105 µV. EMG was monitored in the Hsu, Wang, & Young (2009) study, but again details regarding the method for monitoring EMG and the actual EMG values were not reported. Amplitude normalization was not performed.

Rodriguez, Thomas, & Janky (2018) conducted cVEMP testing on 10 young, healthy children (mean age 6.5), 10 adolescents (mean age 13.6), and 10 young adults (mean age of 25.7). The results of this study found that peak to peak amplitude differences between age groups were non-significant, cVEMP latencies were not impacted by age, and EMG contraction level did not vary significantly between pediatric and adult age groups. The respective peak-to-peak amplitude and P1 latency values for the children group were 360.60 µV and 12.25 ms. For the adult group, the respective values were 223.17 µV and 13.92 ms. The peak-to-peak amplitude values for children and adult participants in this study were greater than our values of 103.29 µV and 159.03, respectively. Additionally, the mean EMG contraction level for child participants in this study was 152.41µV, while the child participants in our study had a much smaller mean EMG contraction level of 89.43 µV. Further, young, healthy adults in this study had an average EMG contraction level of 175.50 µV while the adults in our study had an average EMG contraction level of 92.71 µV. The higher peak-to-peak amplitudes and EMG contraction levels among participants in the Rodriguez, Thomas, & Janky (2018) study was likely due to testing position. Participants were asked to lay supine and lift up their head during the testing, which led to optimal muscle contraction, higher levels of EMG, and greater cVEMP amplitudes. In contrast, the participants in our study were in a seated position with their head turned away from the presentation of the stimulus which does not facilitate a muscle contraction as large as if they were to lay supine. Overall, it is likely that variations in testing position led to different peak-to-peak amplitudes and EMG contraction levels among the participants.

McCaslin, Jacobson, Hatton, Fowler, & DeLong (2013) conducted cVEMP testing on 21 child participants (mean age 10.81), 48 young adults (mean age 28.04), and 28 older adults (mean age 52.75), and found results that vary significantly from our study. They reported that cVEMP latency increased with subject age, cVEMP amplitude decreased with subject age, and that variability in the RMS of the prestimulus EMG decreased with subject age. The respective cVEMP latency, amplitude, and EMG values for the child participants were 14.24 ms, 623.43 µV, and 350.81 µV. The respective cVEMP latency, amplitude, and EMG values for the young adult participants were 15.42 ms, 358.54 µV, and 318.53 µV. In contrast, the results of our study showed that subject age did not have an impact on cVEMP latency, amplitude, or EMG contraction levels. It is possible that the difference in mean participant age impacted the results of each of the studies. The McCaslin, Jacobson, Hatton, Fowler, & DeLong (2013) study had a mean participant age of 10.81, while our study had a much smaller mean participant age of 3.71. Additionally, we studied participants in a seated, head-turned position because that is what is used in pediatric vestibular clinics. In contrast, McCaslin, et al. (2013) ran participants in a semi-recumbent position, almost supine, with the head turned and lifted. They reported very high EMG values upwards of 300 µV in their pediatric group (i.e. mean age 10) that were greater than our values of ~90 µV in a group with a mean age of 3. It is likely that the different testing positions used in each of these studies impacted the EMG contraction levels of the child participants. Overall, the differences in age and in testing position makes it difficult to compare our results to this study.

Similar to our analysis, McCaslin, et. al (2013) found that EMG monitoring and amplitude normalization did not result in decreases to interaural amplitude asymmetry (IAA) ratios that were statistically significant. This study did, however, provide individual cases where normalizing data resulted in abnormal IAA becoming normal, or a normal IAA becoming abnormal. This phenomenon was also observed in our data and is illustrated in **Table V** of the results section. Although there is no statistical evidence to support the use of EMG monitoring and amplitude normalization when performing a cVEMP, the individual cases of IAA changing from normal to abnormal or abnormal to normal after using these techniques provides evidence that they hold clinical relevance.

Limitations

A limitation of this study is the small pediatric age group sample size. Data collection is ongoing to increase the number of participants in the pediatric group.

Future Studies

In the future, I would like to examine the variability of EMG over the duration of the recording. In other words, I would like to know to what extent EMG fluctuates throughout the recording. Anecdotally, most adults were very steady during the recording with little visible changes in the tonic contraction of their SCM. Similarly, many children were very steady during the recording as they stared intently at the iPad. However, some children tended to wiggle or shift positions as they were sitting alone or on their parent's lap.

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