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Role of EMG monitoring on cVEMP testing in preschool age children

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Role of EMG Monitoring on cVEMP Testing in Preschool Age Children

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Abstract

While cervical vestibular evoked myogenic potential (cVEMP) testing has largely been studied and practiced on the adult population, less is known about the best practices for performing cVEMPs on a pediatric population, especially in young children under the age of 5 years. Further, very young children (i.e., 2-3 years) often prefer to sit with their caregiver during the testing, yet there is very little data on how much electromyographic (EMG) activity a child generates if in a seated position as opposed to a supine position. The purpose of this study was to assess the role of EMG on cVEMP recordings in pre-school aged children in a seated, head-turned position. Additionally, the pediatric data was then compared to a cohort of normative adult cVEMP results to determine if there were significant differences between the groups. We collected cVEMPs in a sample of children ages 3 – 5 years using an air-conducted 500 Hz tone burst. Children sat upright either alone or in their care giver's lap. Results showed the levels of tonic EMG in a seated, head-turned position were adequate to generate a cVEMP that was symmetrical between sides and comparable to adult data. While there was no observable effect of amplitude normalization techniques on cVEMP mean interaural amplitude asymmetry, amplitude normalization reduced intersubject variability and there were individual cases where monitoring and correcting for EMG made a clinically significant difference in test interpretation.

Introduction

Vestibular Evoked Myogenic Potential Testing

Vestibular evoked myogenic potential (VEMP) testing stimulates the vestibular system using high sound pressure stimuli, bone conducted vibration, or galvanic stimulation delivered to the patient's ear while measuring the resulting myogenic muscle response (Rosengren, 2015). The vestibular system houses two otolith organs, the utricle and saccule, within which is the sense organ known as the macula (Lysakowski, McCrea, & Tomlinson, 1998; McCaslin & Jacobson, 2013). The macula holds two types of vestibular hair cells that transform mechanical displacement into electrical energy triggering the sensation of linear motion (Lysakowski, McCrea, & Tomlinson, 1998; McCaslin & Jacobson, 2013). High sound pressure stimuli will displace the macula shifting its weight thereby shearing the hair cells and stimulating the vestibular system as if the individual had moved linearly (McCaslin & Jacobson, 2013). If using air conduction, the most effective presentation of the stimulus is through short 500 Hz tone bursts as they result in the greatest VEMP amplitude (Meyer et al., 2015).

Cervical VEMPs (cVEMPs) are a type of VEMP used clinically to measure the function of the saccule by way of placing an electrode on the sternocleidomastoid (SCM) muscle (Colebatch & Halmagyi, 1992 & Colebatch, Halmagyi, & Skuse, 1994). The saccule has an afferent pathway through the inferior vestibular nerve, a central connection in the vestibular nucleus, and an efferent pathway through the medial vestibulospinal tract to the spinal accessory nucleus of cranial nerve XI which is responsible for innervating the motor neurons of SCM muscle (Rosengren, 2015). Due to

these connections, electrodes can be placed directly on the SCM to determine the function of the saccule and inferior portion of the vestibular nerve.

The cVEMP is an ipsilateral response meaning the response is measured from the same side the stimulus is presented to (Colebatch, Halmagyi, & Skuse, 1994). Additionally, it is an inhibitory response meaning a release of contraction of the SCM in response to stimulation is required to observe a response (Colebatch & Rothwell, 2004). Colebatch & Rothwell (2004) found that with increased muscle contraction the resulting muscle inhibition grows leading to a larger cVEMP response. For this reason, when testing cVEMPs the patient must contract their SCM muscle an adequate amount before presenting the stimuli so the release of muscle contraction during the recording can be observed (Rosengren, 2015). There are several ways to achieve SCM muscle contraction, the most common being supine head lifted, supine head turned and lifted, and seated head turned. A study done by Isaacson, Murphy, and Cohen in 2006 compared the 3 common methods of SCM activation and found that a supine position with the head turned and lifted away from the test ear results in the largest response amplitude.

cVEMPs and EMG

Electromyography (EMG) indicates how much a muscle is contracted. Muscle contraction can be measured by placing an electrode on a muscle and observing changes in EMG as contraction increases and decreases. As mentioned, for cVEMP testing an electrode is placed on the SCM muscle to monitor contraction via EMG amounts during testing. Because cVEMPs are an inhibitory response a fair amount of muscular contraction is required prior to the start of the cVEMP recording – this is demonstrated by the EMG value reported in microvolts through the EMG monitoring electrode. The

greater the EMG generated by the SCM, the greater the resultant cVEMP amplitude (Akin et al., 2004; McCaslin, Fowler, & Jacobson, 2014). This amplitude measure is then used to calculate interaural amplitude asymmetry (IAA) which calculates the difference in cVEMP amplitudes between the right and left sides. Clinically, if an individual's IAA falls outside of the designated cut-off value their result would be significant for a vestibular asymmetry.

This highlights the importance of monitoring for EMG during cVEMP testing. If the amount of EMG is not monitored between patients right and left sides, a large discrepancy may be missed (Akin et al., 2004; Bogle et al., 2013). For example, the patient's right side may generate a large amount of EMG resulting in a large cVEMP on the right while their left side generates a small amount of EMG resulting in a small cVEMP. If EMG amounts are not monitored, or amplitude not corrected for EMG, an erroneous conclusion may be drawn that the patient has a vestibular weakness on the left side stemming from the saccule or inferior vestibular nerve (Akin et al., 2004; Bogle et al., 2013). For these reasons, EMG should be monitored, and many recommend amplitude correction during cVEMP testing, at least in adults (Akin et al., 2004; McCaslin, Fowler, & Jacobson, 2014).

When EMG is monitored, amplitude normalization, also referred to amplitude correction, can be used to remove EMG as a factor in the results and more objectively compare the vestibular function between sides. There are several ways to normalize amplitude, a common method involves dividing the average EMG generated during the cVEMP recording into the final cVEMP amplitude (Lee et al, 2008; McCaslin et al, 2013; McCaslin, Fowler, & Jacobson, 2014; McCaslin & Jacobson, 2013). Although

there are several methods to monitor for EMG in this way, one of the more common ways is to place an additional electrode directly below the active electrode on the SCM that can then be used to actively measure the EMG of the SCM in a pre-stimulus period.

Vestibular Development in Adults and Children

The cVEMP is driven by the vestibulocollic reflex (VCR) which kicks in at birth and uses information from the vestibular system to act on the neck muscles stabilizing the head (Colebatch & Rothwell, 2004; Lysakowski, McCrea, & Tomlinson, 1998). Since this system is fully developed at birth, we would not expect to see differences in cVEMPs obtained from adults and children if the same protocols were used to obtain VEMPs in both populations. However, differences may arise due to the difference in size between SCM muscles in adults and children which may lead to differences in achieved muscle contraction. Aside from this, we could expect a VEMP obtained from a preschooler to look like a VEMP obtained from an adult. However, the traditional supine head lifted and turned protocol may not be practical when testing preschool children. They are often not comfortable laying supine in an unfamiliar environment while being asked to turn their head and lay still. It is important to investigate whether alternative means of achieving SCM contraction without requiring a supine position generate adequate amounts of EMG for cVEMP testing.

In infants, absent VEMPs are associated with motor development delays like sitting up and walking later in life (Verrecchia et al, 2019). In older preschool age children present cVEMPs generally result in better static balance compared with children who have absent cVEMPs (Shall, 2009). However, this relationship between present cVEMPs and improved balance is not consistently observed. One likely reason for this is

that there is not a consistent protocol in place for assessing VEMPs in a preschool age group. There are differences with EMG monitoring protocols, body and head placement, electrode placement discrepancies, among other things. This renders it nearly impossible to draw definitive conclusions about the relationship of cVEMPs between adults and children, as well as the relationship of cVEMPs among the pediatric population alone.

Importance of VEMPs in Children

Undiagnosed vestibular disorders in children can lead to delays in language acquisition as well as delays in motor function development and postural control (Maes, De Kegel, Van Waelvelde, & Dhooge, 2013; El-Danasoury, El Sirafy, Taha, & Hegazy, 2015; Pereira et al., 2015). This can result in anxiety and social withdrawal as the child reaches their preschool years. This makes an early and accurate diagnosis of vestibular disorders extremely important for young children (Pereira et al., 2015). However, many children may not be able to report their symptoms making objective testing the gold standard for pediatric balance disorder evaluations. The challenge with testing this population is that clinically appropriate tests for adults may not be as appropriate for children due to differences in tolerance for discomfort, normative data, and even recording parameters (Maes et al., 2013).

VEMPs are a noninvasive, and easily tolerated vestibular test that can provide critical information on vestibular function in a short amount of time (Pereira et al., 2015). When comparing VEMP testing to other traditional vestibular function tests such as calorics the advantage is clear. Caloric testing involves administering a stream of either water or air at different temperatures to stimulate the horizontal semicircular canal often eliciting a sensation of spinning (Fife et al, 2000). This sensation can be frightening to

children and may result in a potential meltdown preventing the clinician from getting a complete picture of the vestibular function and ultimately requiring a follow up visit (Abdullah et al, 2017; El-Danasoury et al, 2014; Hsu, Wang, & Young, 2009; Kelsch, Schaefer, & Esquivel, 2006). In contrast, air conduction VEMP testing involves placing electrodes on the child's skin and transmitting a loud sound to one ear for a very brief time while the child turns their head. The most common air conduction VEMP stimuli is a 500Hz tone burst presented at 125dB pSPL at a rate of 5.1/second for a designated number of sweeps (Meyer et al., 2015). The entire test takes about 30 seconds per ear and does not elicit a dizzy sensation like caloric testing. VEMP testing is beneficial in all age groups because each ear is assessed separately, and the test is quick and noninvasive.

Pediatric cVEMPs in the Literature

Although cVEMPs can be tested on infants as young as one week old, very few pediatric cVEMP studies include children under the age of 5 (Erbek et al, 2007; Verrecchia at al, 2019). A review of pediatric cVEMP articles from the past 16 years shows the majority either do not report an average age range at all, or report on participants with an average age around 7.7. Only 8 articles looked at cVEMPs in children under the age of 5, and of those 4 reported on EMG during the cVEMP recording. It has been shown that children over the age of 5 can be tested using a standard adult protocol, but less is known about the best practices for testing preschool age children (Abdullah et al, 2017; Beshr et al, 2019; El-Danasoury et al, 2014; Kaya et al, 2021; Pereira et al, 2014). Children often prefer to sit on their caregiver's lap during testing, but much of the literature has patents in a supine position as this has been reported to generate maximal EMG when testing adults (Wiener-Vacher & Zhou, 2013).

There is not a lot of research on whether a seated position will generate an adequate amount of SCM contraction required for a cVEMP test. Wiener-Vacher & Zhou (2013) reported that children can sit on their caregiver's lap and be enticed to turn their head with a visually interesting toy, thereby inducing SCM contraction for the duration of the recording. Despite showing positive results, this is currently not a standardized method for utilizing a seated head turned position when testing preschool age children.

Those studies that do include children 5 and younger often do not include EMG monitoring or amplitude normalization citing reasons such as intolerance for an additional electrode or limited physical space on the SCM (Kelsch, Schaefer, & Esquivel, 2006; Valente, 2007). This is a significant gap in the literature as it has been shown the EMG monitoring and amplitude normalization should always be calculated to correct for differences in muscle contraction to isolate true vestibular weakness. Further, studies that do include preschool age children and report utilizing EMG monitoring or amplitude normalization typically have an average participant age reflecting adolescence, or do not report the average age at all, indicating a very small number of preschool participants included (Hsu, Wang, & Young, 2009; Kelsch, Schaefer, & Esquivel, 2006; Maes et al, 2013; Picciotti et al, 2007). It is important to investigate whether the seated, head turned position utilizing EMG monitoring and amplitude normalization can result in adequate and symmetric EMG through the duration of the cVEMP recording for a preschool population.

Design and Methods

Participants

Twelve pediatric participants ages 3-5 (mean age =3.89(0.782), 8 females & 4 males) were recruited for this dissertation. The recruitment process for the pediatric population was conducted through an email blast sent to the James Madison University faculty stating the need for participants in this age range. Data from a cohort of seventeen adult participants ages 20-23 (mean age =20.59(0.795), 15 females & 2 males) was also collected prior to the start of this dissertation under the same procedural guidelines.

Exclusionary criteria for both the pediatric and adult participants included individuals with balance disorders and those with abnormal middle ear function. All participants underwent and otoscopic examination and a tympanometry screening prior to cVEMP testing to rule out abnormal middle ear function or excessive cerumen.

Procedures

Data Gathering. cVEMP responses were elicited with a 125 dB pSPL, 500Hz Blackman-gated tone burst presented via air conduction using an Otometrics Chartr EP 200 (Natus Medical Incorporated, Denmark). The tone burst had a 2 ms rise/fall time and a 0 ms plateau and was presented at a rate of 5.1/second. The stimulus was presented in one ear at a time through Etymotic ER-14B disposable foam eartips. The tone burst was played in the participant's ipsilateral ear while their head was turned in the opposite direction (Figure 1).

Disposable silver/silver-chloride electrodes were applied to the surface of the participant's skin using a conventional clean electrode preparation technique. This

included prepping the skin with an alcohol wipe and nu-prep jelly to scrub the skin prior to electrode placement. To identify the SCM, the child was asked to turn their head and the mid-portion of the SCM was identified (Figure 1). Six electrodes were placed on each participant, two electrodes placed vertically on both the right and left SCM, the active electrode above and the EMG monitoring electrode below, one ground electrode on the forehead, and one reference electrode on the sternum. Electrode impedance was measured after each participants electrode placement to ensure the electrodes effectively conducted the muscle signal.

Each participant had cVEMP testing conducted in an upright, seated position. The pediatric participants were given the choice to either sit independently or sit in a caregiver's lap. An iPad playing children's shows was displayed to the pediatric participants as a means of achieving a head turn, effectively contracting the SCM muscle (Figure 1). The cVEMP recording was started once a head turn was achieved and was paused if the child's head returned to center. The recording was resumed once their head returned to face the iPad. The bioelectrical activity from the participants SCM was amplified and filtered (5-500 Hz) with a commercially produced neurophysiological recording system. For each recording, the EMG activity was digitized at a rate of 5000 Hz and recorded. An EMG monitor was connected to the electrodes and displayed the amount of muscle contraction to the investigator in real time.

Figure 1: Child sitting upright showing SCM flexed on the left panel and placement of the active electrode and EMG electrode directly below shown on the right panel. iPad is shown on the right panel for the child to watch as they turn their head. The stimulus is played in the right ear, recordings made from the right SCM, while the child turns their head to the left.

cVEMPs were recorded from both the right and left side, separately, and all sweeps were accepted, regardless of the amount of muscle contraction. The amount of EMG generated was recorded for each participant. The final EMG value is the average EMG collected over the duration of the recording period. The first positive peak (P1) and negative peak (N1) of the waveform were labeled (Figure 2) for each participant's right and left side. The peak-to-peak amplitude of the cVEMP was tabulated and the corrected cVEMP amplitude was calculated by dividing the raw amplitude by the average EMG during the recording. In addition to EMG and amplitude, P1 latency values were tabulated and interaural amplitude (both corrected and uncorrected) and interaural latency measures were calculated. Each cVEMP trial ran for a duration of 80 accepts. In-between

testing trials the iPad was brought back to center allowing the pediatric participants to pause contraction and relax their neck.

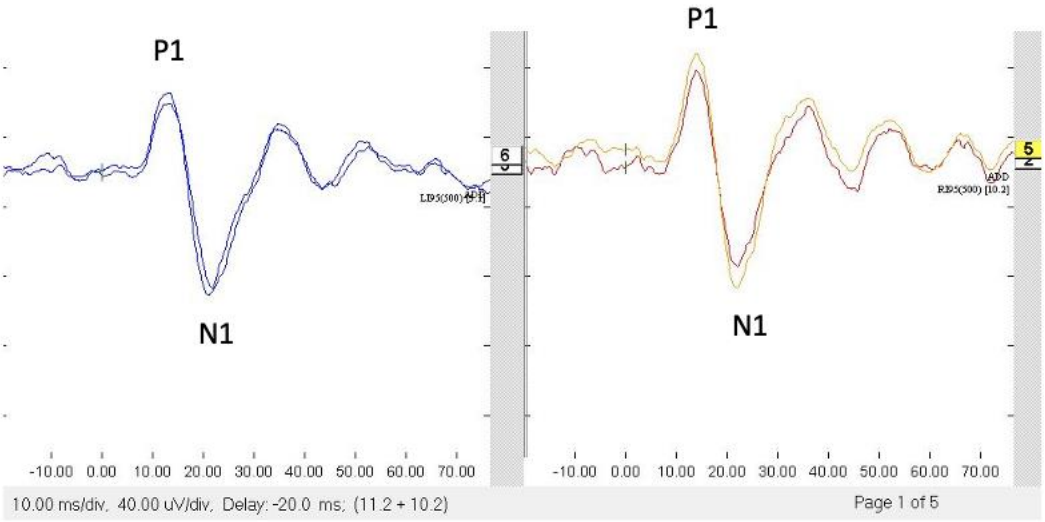

Figure 2: Pediatric cVEMP waveform example. Left cVEMP shown in the left panel in blue and the right cVEMP shown in the right panel in red and yellow. The P1 and N1 peaks are labeled.

Data Analysis and Interpretation. Variables of latency, interaural latency difference (ILD), EMG (including overall, range, average, and symmetry), raw peak to peak amplitude, normalized peak to peak amplitude, uncorrected interaural amplitude asymmetry (IAA), and corrected interaural amplitude asymmetry were reported separately for both the pediatric and adult groups. ILD is calculated by taking the absolute value of the difference in P1 latency from the right and left cVEMPs. The ILD measurement can determine if there is a significant difference in cVEMP latency between sides. IAA is calculated using the formula ((amplitude right – amplitude left)/(amplitude

right + amplitude left))*100. Normal limits for IAA are typically reported as cut-off values (i.e., mean + 2 standard deviations). If an individual's IAA falls outside the cut-off value, the finding would be significant for a vestibular asymmetry. Descriptive statistics were calculated for the means and standard deviations of each variable. A group comparison was then made between the pediatric and adult data using a t-test. Variables compared were amplitude, corrected amplitude, EMG, latency, IAA, and corrected IAA. Statistical measures were run on SPSS version 28.0.0.0.

Results

After completion of testing, data from 3 of the 12 pediatric participants was excluded. One participant had an abnormal cVEMP in one ear, the second participant had no measurable cVEMP response, and the third had an abnormally large asymmetry between ears. This resulted in a total pediatric participant population of 9. The adult group had a total population of 17.

Descriptives

The average cVEMP amplitude, corrected amplitude, EMG, IAA, and corrected IAA for both the pediatric and adult groups are shown below in Tables 1&2.

Age Group	Amplitude (µV) Right ear	Amplitude (µV) Left ear	Corrected Amplitude Right Ear	Corrected Amplitude Left Ear	EMG (µV) Right Ear	EMG (µV) Left Ear
Pediatric	86.31 (36.31)	144.49 (72.88)	0.98) (0.38)	1.63 (0.65)	91.33 (30.39)	100.89 (47.61)
Adult	159.03 (71.65)	176.95 (86.63)	1.82 (.71)	1.97 (0.78)	92.71 (37.83)	91.24 (29.86)

Table 1: Mean (standard deviation) of cVEMP amplitude, corrected amplitude, and EMG.

Age Group	IAA (%)	IAA Cut-off (%)	Corrected IAA (%)	Corrected IAA Cut-off (%)
Pediatric	22.11 (22.74)	67.69	27.27 (14.77)	56.81
Adult	12.80 (11.35)	35.5	15.40 (9.06)	33.52

Table 2: Mean (standard deviation) of cVEMP IAA, corrected IAA, and cut-off values.

A series of paired sample t-tests were completed to determine if there were ear effects for both the pediatric and adult groups using a criterion of $p < 0.05$. Results showed no significant effects of ear for EMG in both the pediatric and adult group (pediatric: $t(8) = -0.598$, $p=0.566$; adult: $t(16) = 0.124$, $p=0.885$). For the adult group there was no significant ear effect for uncorrected and corrected amplitude (uncorrected: $t(16) = -1.062$, $p=0.304$; corrected: $t(16) = -0.881$, $p=0.391$). However, in the pediatric group the right ear amplitude was significantly smaller than the left for both the uncorrected and corrected measures (uncorrected: $t(8) = -2.421$, $p=0.042$; corrected: $t(8) = -3.582$, $p=0.007$).

The average P1 latency and ILD for both the pediatric and adult groups are shown below in Table 3. There was no significant difference found between right and left ears for both the adult and pediatric groups (adult: $t(16) = 0.399$, $p=0.695$; pediatric: $t(8) = -0.070$, $p=0.946$).

Age Group	P1 Latency Mean (SD) Right Ear	P1 Latency Mean (SD) Left Ear	ILD (SD)	ILD Cut-off
Pediatric	14.33 (1.50)	14.39 (1.53)	2.02 (1.02)	4.06
Adult	16.07 (2.68)	15.86 (2.39)	1.49 (1.64)	4.77

Table 3: cVEMP latency data in milliseconds with cut-off values

Pediatric vs Adult Data

There were significant group differences for the corrected and uncorrected amplitude in the right ear (corrected: $t(24) = 3.264$, $p=0.003$, uncorrected: $t(24) = 2.839$, $p=0.009$), with significantly smaller amplitudes observed in the pediatric group. No significant differences between groups were observed in the left ear (corrected: $t(24) = 1.108$, $p=0.279$; uncorrected: $t(24) = 0.957$, $p=0.348$).

Corrected IAA was significantly smaller in adults, meaning there was more symmetry between the right and left sides for the adult group ($t(24) = -2.550$, $p=0.018$). The same was not observed with uncorrected IAA ($t(24) = -1.406$, $p=0.172$).

There were no significant p1 latency differences between the adult and pediatric groups (right ear: $t(24) = 1.798$, $p=0.085$; left ear: $t(24) = 1.666$, $p=0.109$). Similarly, there was no significant difference in ILD between the pediatric and adult groups ($t(24) = -0.873$, $p=0.391$).

EMG

As expected, for both groups as EMG increased the cVEMP amplitude also increased. This was seen in both ears for both age groups. Figures 3&4 below help to illustrate this linear trend between EMG and amplitude observed in both groups.

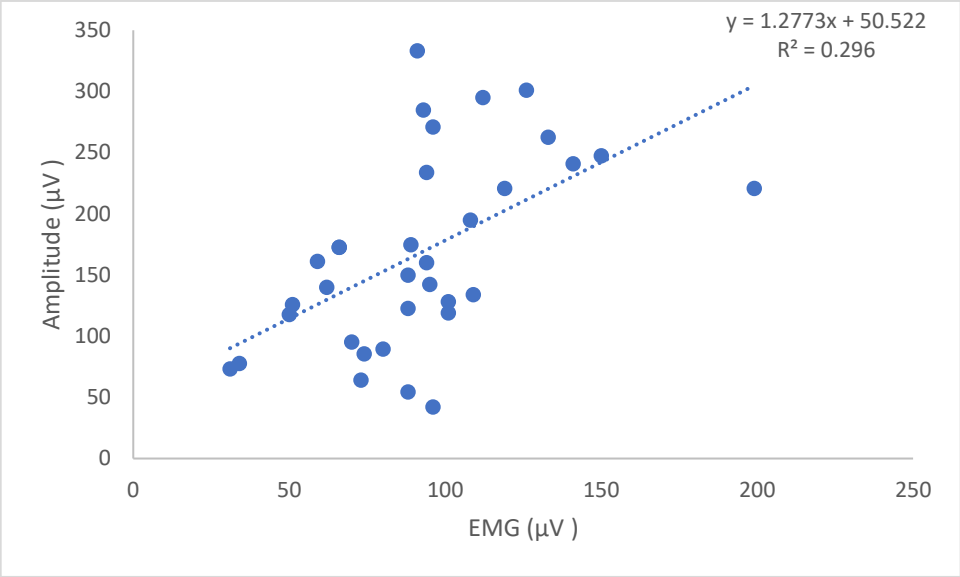

Figure 3: Adult amplitude as a function of EMG with linear regression.

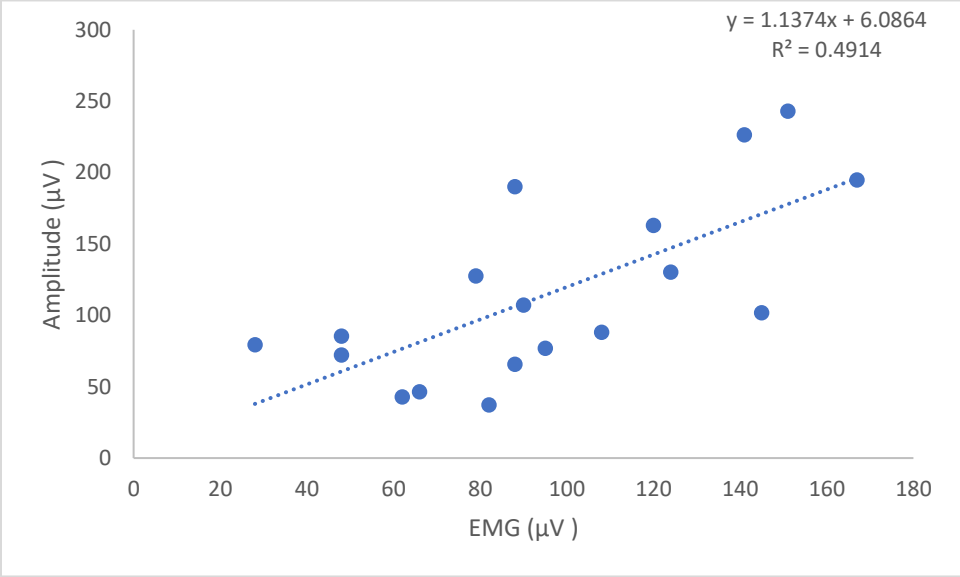

Figure 4: Pediatric amplitude as a function of EMG with linear regression.

As stated above, there were no significant ear effects for EMG in both the pediatric and adult data. Additionally, no significant difference in EMG was observed between the adult and pediatric groups for either ear (right ear: $t(24) = 0.094$, $p=0.926$; left ear: $t(24) = -0.637$, $p=0.530$). The EMG produced by the adult group ranged from

34µV to 199µV with an average EMG of 92.71µV in the right ear and from 31µV to 150µV with an average EMG of 91.24µV in the left ear. For the pediatric group, EMG ranged from 48µV to 145µV with an average EMG of 91.33µV in the right ear and from 28µV to 167µV with an average EMG of 100.89µV in the left ear. One adult outlier generated 199µV in his right ear, higher than all other participants by 66µV, (see figure 5). The largest difference in EMG generated by the pediatric group is only 25µV. Right and left ear EMG data for the pediatric and adult groups can be seen below in figures 5 & 6.

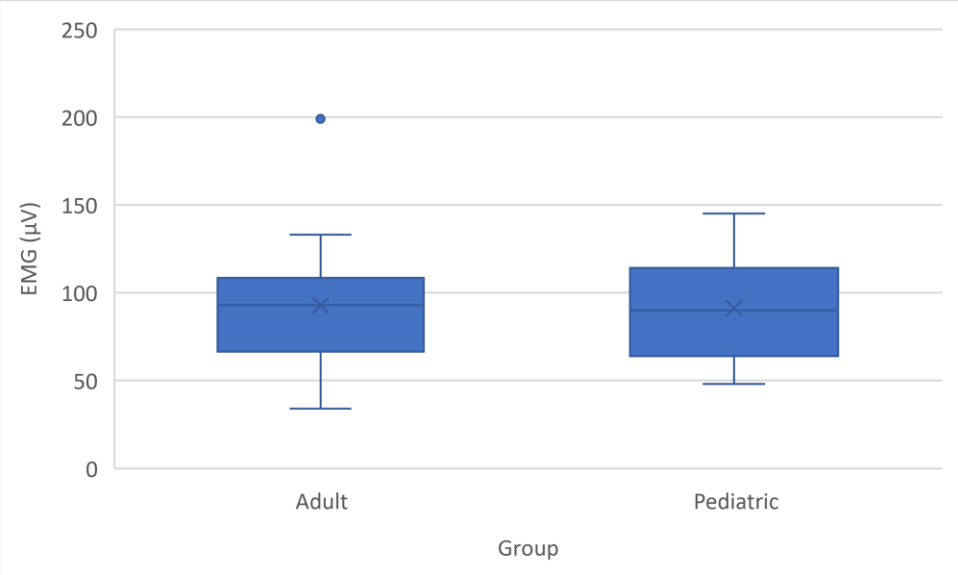

Figure 5: Right ear EMG level by group

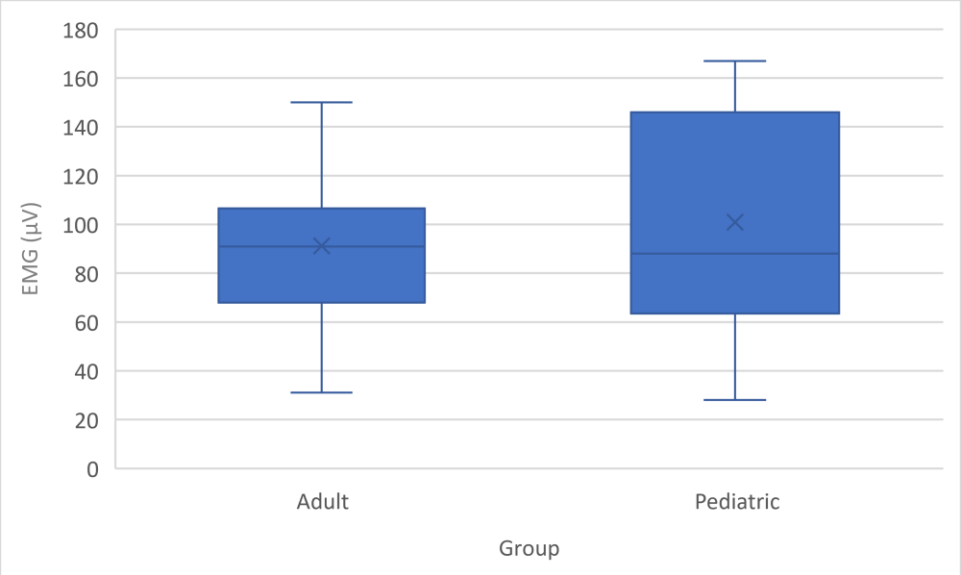

Figure 6: Left ear EMG level by group

Effect of EMG Correction on IAA

A repeated measures ANOVA was performed to determine whether correcting cVEMP amplitude significantly affected the resultant IAA. It was found that there was no significant effect of EMG correction on IAA for both the adult (F = 0.814, df = 1, p = 0.380) and the pediatric (F = 0.662, df = 1, p = 0.439) participants.

Discussion and Conclusion

There is limited data investigating the role of EMG on cVEMP testing in preschool age children while in a seated position. Our study showed that 3–5-year-old children easily tolerated a seated head turned position with the additional EMG monitoring electrode and were able to generate EMG that symmetrical between right and left sides. Further, the resulting cVEMPs were comparable to those obtained by a group of adult participants tested in the same position. This indicates that not only is a seated

head turned position feasible to collecting cVEMPs in preschoolers, but it is likely preferable to a supine position where previous researchers were unable to test children in this age range (Kelsch, 2006; McCaslin, 2013; Picciotti, 2006; & Rodriguez, 2018).

When examining the descriptive data between adults and children in this study it was found that both the adults and the pediatrics generate equal amounts of EMG between the right and left sides. This indicates that preschool age children can generate equal and stable amounts of EMG contraction during cVEMP testing, contrary to what was hypothesized by several previous studies (Kelsch, Schaefer, & Esquivel, 2006; Valente, 2007). Additionally, there was no significant difference in EMG between the adult and pediatric group indicating that not only can pediatric participants generate symmetric amounts of EMG, but they are also comparable to EMG amounts generated by adults. Additionally, it is known that in adults and older children as EMG increases, the resultant cVEMP amplitude increases as well. This study showed the trend between EMG and cVEMP amplitude is accurate in preschool children as well. Both the adult and the pediatric participants data showed an upwards trend in data – as EMG increased the resulting cVEMP amplitude increased as well. This shows consistency between pediatric and adult participants and further highlights the importance of monitoring for EMG during cVEMP testing even when working with children as young as 3-5 years old.

The same was found for P1 latency and ILD in both the adult and pediatric groups. There was no significant difference noted in P1 latency and ILD between the right and left ears or between the two groups. This further indicates that pediatric participants can perform cVEMP testing like an adult participant and generate reliable results between the right and left sides.

When examining the amplitude results it was found there was no significant difference between right and left sides for both uncorrected and corrected amplitude for the adult group. However, the same was not found for the pediatric group. For both the uncorrected and corrected amplitude measures the pediatric group showed significantly smaller right ear amplitudes when compared to the left ear. Figures 7 and 8 illustrate the trend for significantly smaller right ear amplitude results for both the uncorrected and corrected amplitude results. The line of equality can be seen in both figures representing equal right and left ear amplitudes. For both the uncorrected and corrected amplitude results, 7 of the 9 pediatric participants had smaller right ear amplitudes.

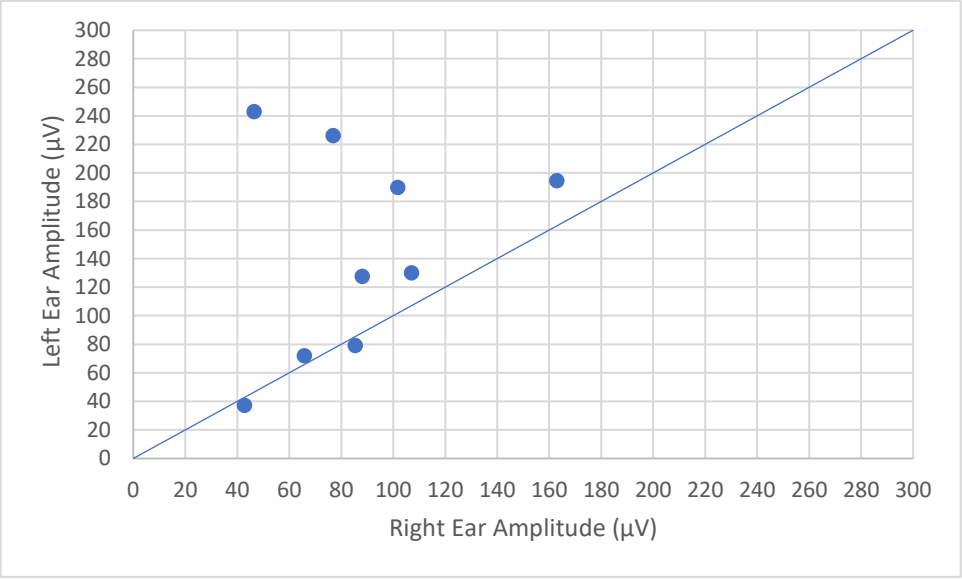

Figure 7: Pediatric right and left ear amplitude results

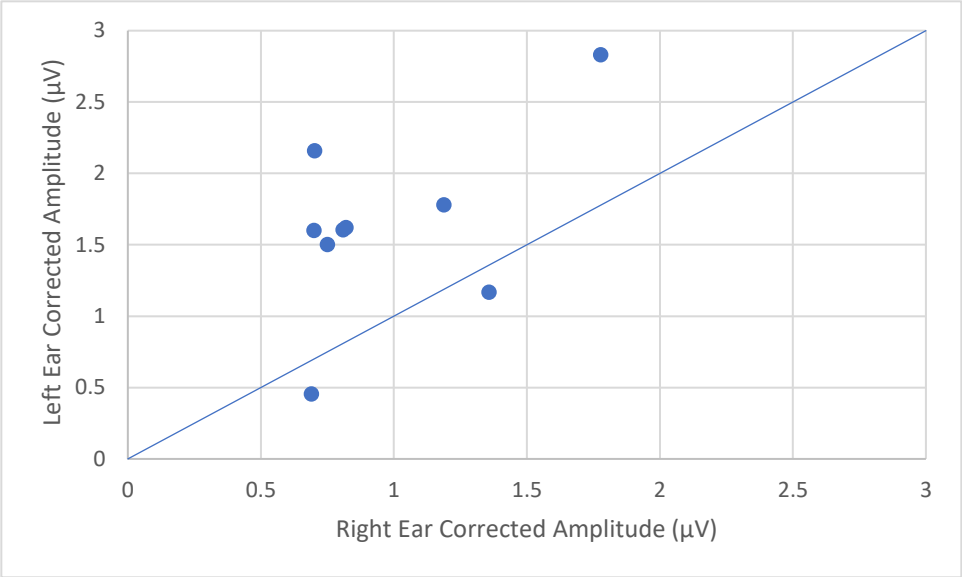

Figure 8: Pediatric right and left ear corrected amplitude

A review of the literature on pediatric cVEMP testing did not reveal similar findings, and instead typically reported no ear effects noted for amplitude measures (Abdullah et. al, 2017; Beshr et. al, 2019; El-Danasoury et. al, 2015; Pereira et. al, 2015; Picciotti et. al, 2007). This translated to the between group results as well. While there was no difference in left ear corrected and uncorrected results between groups, for both corrected and uncorrected results in the right ear the pediatric group had significantly smaller amplitudes compared to adults. This is likely due to the difference noted in pediatric right ear amplitude measures discussed above. As similar ear effects for amplitude were not found in the adult group, and protocols and equipment were kept consistent between groups, a technical error cannot be ruled out as a contributing factor to the pediatric amplitude results.

Finally, although there was no difference in uncorrected IAA between the adult and pediatric participants, corrected IAA was significantly smaller in adults. This means

there was less asymmetry between sides for adults compared to pediatrics after amplitude normalization was performed. Additionally, no significant difference was found on IAA between uncorrected and corrected cVEMP amplitude in both the pediatric and adult groups. However, a difference was noted on an individual level relative to the resulting changes in cut-off values. The corrected IAA cut-off values were lower than the uncorrected IAA cut-off values for both groups. This effectively tightens the normative data criterion meaning there are stricter values to be considered normal or abnormal for IAA. The benefit of this tightened criterion can be seen in pediatric group subject number PCV 7. This participant had an uncorrected IAA of 67.9% and a corrected IAA of 39.2%. Using the uncorrected cut-off value this child's IAA would be considered abnormal. However, using the corrected cut-off value the IAA becomes normal. If corrected IAA had not been used, this child would have been erroneously diagnosed as having a vestibular weakness on one side due to a difference in EMG contraction between sides rather than a true saccular weakness. Another example highlighting the importance of monitoring for EMG can be seen with pediatric participant number PCV 6. They initially had an IAA value of 30.2% which is considered grossly normal. However, correcting for EMG raised their IAA value to be 50.9% which while still technically considered normal, is much closer to being considered borderline for a vestibular asymmetry.

In conclusion, while there was no significant group effect of amplitude normalization on cVEMP amplitude, it was shown that there is a noted individual effect. This suggests that it is important to monitor and correct for EMG when testing cVEMPs because it may help to rule out differences in EMG contraction and instead identify true vestibular abnormalities. Monitoring for EMG is fast, easy, and well tolerated by young

children. Additionally, this study found that a seated head turned position generated adequate cVEMPs with EMG that is symmetric between sides. Resulting data does not differ from that obtained by adults indicating it is an effective means of performing cVEMP testing in a preschool population.

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