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Maturational Effects of the Vestibular System: A Study of Rotary Chair, Computerized Dynamic Posturography, and Vestibular Evoked Myogenic Potentials with Children

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Abstract

Maturational effects were investigated in two age groups (N = 30 per group) of children with normal hearing sensitivity, using rotary chair (RC), computerized dynamic posturography (CDP), and vestibular evoked myogenic potential (VEMP) measures. Children recruited within the younger group were three through six years of age, and children within the older group were nine through eleven years of age. Data obtained for each pediatric group were compared with clinic and/or published adult normative data for each measure. Significant age effects were seen on many CDP subtests (sensory organization test and motor control test); VEMP latencies; and RC gain, phase, and step velocity measures. The results of this study demonstrate significant maturational effects from preschool age through adulthood and suggest that adult normative data may not be appropriate when interpreting pediatric test results. Since adult techniques should oftentimes not be utilized, a proposed test battery is described that may be efficiently utilized with pediatric patients.

Key Words: Computerized dynamic posturography, pediatric vestibular evaluation, rotary chair, vestibular evoked myogenic potentials

Abbreviations: CCW = counterclockwise; CDP = computerized dynamic posturography; CW = clockwise; EOG = electrooculography; MCT = motor control test; RC = rotary chair; SCC = semicircular canal(s); SCM = sternocleidomastoid muscle; SOT = sensory organization test; SV = step velocity; TC = time constant; VEMP = vestibular evoked myogenic potentials; VOG = video-oculography; VOR = vestibulo-ocular reflex

Sumario

Se investigaron los efectos de la maduración en niños con sensibilidad auditiva normal en dos grupos de edad (n = 30 por grupo), utilizando la silla rotatoria (RC), la posturografía dinámica computarizada (CDP) y mediciones de potenciales evocados miogénicos vestibulares (VEMP). Los niños reclutados dentro del grupo más joven tenían de tres a seis años de edad, y los niños en el grupo más viejo tenían de nueve a once años de edad. Los datos obtenidos de cada grupo pediátrico se compararon con datos normativos de adultos, clínicos y/o publicados, para cada una de las mediciones. Se encontraron efectos significativos de la edad en muchas sub-pruebas de la CDP (pruebas de organización sensorial y pruebas de control motor), en las latencias del VEMP, las medidas de ganancia, fase y velocidad de paso de la RC. Los resultados de este estudio demuestran efectos significativos de

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maduración en niños pre-escolares hasta la edad adulta, y sugiere que los datos normativos de adultos pueden no ser apropiados cuando se interpretan resultados pediátricos. Dado que las técnicas para adultos a menudo no deben ser utilizadas, se describe una batería propuesta de pruebas que puede ser eficientemente usada en pacientes pediátricos.

Palabras Clave: Posturografía dinámica computarizada, evaluación vestibular pediátrica, silla de rotación, potenciales evocados miogénicos vestibulares

Abreviaturas: CCW = contra las manecillas del reloj; CDP = posturografía dinámica computarizada; CW = con las manecillas del reloj; EOG = electro-oculografía; MCT = prueba de control motor; RC = silla rotatoria; SCC = canales semicirculares; SCM = músculo esternocleidomastoideo; SOT = prueba de organización sensorial; SV = velocidad de paso; TC = constante de tiempo; VEMP = potenciales evocados miogénicos vestibulares; VOG = video-oculografía; VOR = reflejo óculo-vestibular

The importance of vestibular evaluation with the pediatric population cannot be overestimated, especially when hearing impairment and/or vestibular symptoms exist. Vestibular impairment may occur comorbidly with numerous childhood disorders. Examples of these disorders are sensorineural hearing impairment (Brookhouser et al, 1982; Cyr et al, 1986; Huygen et al, 1993; Rine et al, 2000), childhood benign paroxysmal vertigo (Mira et al, 1984a; Mira et al, 1984b; Ansink et al, 1985), and a myriad of childhood syndromes (Wang et al, 1981; Young et al, 1996; Wiener-Vacher et al, 1998; Guyot and Vibert, 1999; Abadie et al, 2000). Erbek et al (2006) studied vertigo in 50 children, finding migraine syndrome to be the most frequent cause. Wiener-Vacher (2004) stressed the importance of recognizing common clinical signs, with vestibular dysfunction most commonly arising from migraine equivalent, ophthalmologic disorder, benign vertigo, and temporal bone fractures. Although vestibular techniques have not been readily available when testing young children, it is crucial that methods be developed to more accurately measure these young systems. This is especially true in view of challenges experienced when attempting standard electrooculography (EOG) with this population. Some investigators have described modification of adult vestibular evaluation techniques (Cyr, 1980; Cyr, 1983), but these have not been widely used on either a research or clinical basis. More recently, Weiss and Phillips (2006) described identification of vestibular dysfunction with five pediatric subjects through use of sinusoidal rotation, step velocity, dynamic visual acuity, observation of post headshake nystagmus, computerized dynamic posturography, and relevant case history details.

In addition to establishing pediatric techniques, it is important to collect pediatric normative data so that accurate interpretation of pediatric test results may occur. Purposes of the current investigation are to (1) describe a vestibular test battery that may efficiently be utilized with children from three through eleven years of age, (2) study this test battery with normal-hearing children prior to evaluating its use with children demonstrating disorders, and (3) evaluate age-related effects on vestibular function tests. In addition, this study compares pediatric results with adult normative data, augmenting existing pediatric normative data.

It is the author's experience that positional testing and bithermal caloric irrigation subtests of EOG have proven challenging when attempted with young children. A number of researchers have investigated maturation effects of nystagmic response during rotation (per-rotary) in young children (Eviatar et al, 1974; Eviatar et al, 1978). Although premature infants demonstrate weaker nystagmic response than full-term cohorts, the vestibular systems of premature babies seem to "catch up" by nine months of age. Early researchers studying effects of developmental age on the vestibulo-ocular reflex (VOR) following caloric irrigation have found varying results. Van der Laan and Oosterveld (1974) found low nystagmus frequency and large amplitudes with children, as compared with adults. Andrieu-Guitrancourt et al (1981) discovered that nystagmic beat frequency increases and maximum eye speed decreases as children mature. Stronger responses have been reported in one-month-old versus eleven-year-old children with respect to amplitude and velocity (Ornitz et al, 1979) while other investigators noted more intense response in middle to late middle age (Mulch and Peterman, 1979). Donat et al (1980) concluded that the VOR goes through several developmental stages, with a healthy response developing by several months beyond full term. Fife et al (2000) reported that absence of the VOR by the age of ten months should be considered an abnormal finding. Krejcova et al (1975) reported significant differences between caloric responses of children and adults, with children demonstrating higher frequency of nystagmic beats. These and other investigators stressed the importance of considering these differences when interpreting pediatric versus adult test results (Kenyon, 1988; Levens, 1988).

Current technologies and testing techniques allow expanded evaluation of vestibular function with younger patients, particularly crucial since many children do not tolerate bithermal caloric irrigations. Rotary chair (RC) subtests involve harmonic acceleration of various velocities and durations, primarily for assessment of horizontal semicircular canal (SCC) function. The sensory organization test (SOT), a CDP (computerized dynamic posturography) subtest, assists with evaluation of functional balance and relative contributions of proprioceptive, visual, and vestibular inputs. The motor control test (MCT), another CDP subtest, measures reactions to unexpected disturbances with various-sized perturbations of the support surface in forward and backward directions. Vestibular evoked myogenic potentials (VEMPs), recorded from the contracted sternocleidomastoid muscle (SCM) in response to auditory stimuli, lend valuable information related to saccular function. The following may also be useful tools within the pediatric audiovestibular diagnostic battery: audiologic evaluation, otoneurologic evaluation, thorough case history, and videooculography (VOG) when the child is able to tolerate goggles. Ideally, pediatric evaluation should thoroughly assess SCC and otolith function and should differentially diagnose between peripheral and central nervous system lesions. In addition to helping to determine site of lesion, the ideal battery should provide functional information and help suggest direction for remediation.

Cyr et al (1980, 1983) were at the forefront in modifying adult vestibular techniques for use with children. They filled the visual field for optokinetic (OKN) testing with rotating cartoon characters and used similar cartoon characters for EOG calibration and smooth pursuit testing. Their RC enclosure was decorated to resemble a spaceship, and tasking was accomplished by piping in familiar children's songs and nursery rhymes. Cyr et al (1985) successfully performed RC screening at .08 Hz with premature and full-term infants as young as three months of age. In this study, children were seated on a parent's lap, and an infrared camera was situated within the darkened enclosure for observation of the VOR. Staller et al (1986) also described RC testing with children, although these investigators tested from .01 to 16 Hz. They found that nystagmus was not present in very young children at .01 Hz but was elicited by the age of 10 months. Phase differences found in subjects younger than four years of age indicated that the VOR was still developing at this age.

A number of studies have also described successful performance of CDP subtests with children, primarily involving the SOT. These subtests measure functional balance and organization of the following cues for regaining and maintaining balance: visual, vestibular, and somatosensory. Six SOT conditions may be described as follows:

Condition #1: Eyes open, platform and visual surround stable

Condition #2: Eyes closed, platform stable

Condition #3: Eyes open, platform stable, and visual surround referenced to one's own sway pattern (sway-referenced)
Condition #4: Eyes open, platform sway-referenced, and visual surround stable
Condition #5: Eyes closed, platform sway-referenced
Condition #6: Eyes open, platform and visual surround sway-referenced

DiFabio and Foudriat (1996) reported that a child as young as three years of age may be tested through use of CDP techniques. Even a child this young will utilize shear forces for balance while ignoring misleading inputs, although these investigators reported that these skills will develop further as the patient ages. Hirabayashi and Iwasaki (1995) found that somatosensory function in children reaches adult levels by three to four years of age, and the visual system develops to adult acuity by 15 years of age. They found that the vestibular system is the last system to develop, that postural stability increases with age, and many children have not reached adult developmental levels by 15 years. Shimizu et al (1994) studied SOT subtests with children from six to thirteen years of age, finding that pediatric scores significantly differed from adult scores in many subtest conditions. Male scores increased with age while female scores remained relatively constant after seven years. Ionescu et al (2006) compared Balance Quest results of 12-year-old children with adult normative data. Mean stabilizing percentages for children were significantly poorer than for young adults, especially when visual information was compromised. The authors described their findings as supporting findings reported in existing CDP literature. According to Cyr et al (1988), CDP testing is indicated with a history of imbalance, when children exhibit "clumsiness," neurological impairment, and suspected organic disease. Rine et al (2000) conducted CDP studies with three- to seven-year-old children, finding that the SOT provides stable and useful measures of the sensory systems and of maturational changes with this population.

VEMPs have recently been reported with the adult population, adding an objective measure of otolith function. Colebatch and Halmagyi (1992) recorded the VEMP from the SCM and demonstrated that the response is of vestibular origin. The VEMP is seen in response to an auditory stimulus presented via insert earphone to the ipsilateral side. The tracing reveals a positive peak (P1) and a negative peak (N1). The important test parameters are the P1 and N1 latencies and the difference in amplitude between P1-N1.

Various investigators have researched the origin of these evoked responses and have traced them to saccular function (Colebatch and Halmagyi, 1992; Halmagyi and Colebatch, 1995). The response is not cochlear in origin, in that the VEMP has been effectively recorded in patients with profound, sensorineural hearing impairment. Sheykholeslami et al (2005) successfully recorded VEMPs with 12 normal neonates and 12 with various clinical findings. They concluded that the pediatric VEMP morphology is similar to that of adults, although they found a shorter latency of the N peak and wider amplitude variability. Kelsch et al (2006) also successfully recorded the VEMP in children from 3 to 11 years of age. Mean latency data in this study also suggested a shorter initial negative peak, consistent with prolongation effects of aging. They concluded that VEMP is a well-tolerated test for screening vestibular function in young children.

It is important to consider a time-efficient, noninvasive, accurate, and comfortable test battery for vestibular assessment with all ages of children. The earlier a vestibular disorder is identified, the sooner remediation strategies can be implemented. Consideration of the above points has given rise to the current study, where various adult techniques have been successfully adapted for use with normal-hearing children. Specifically, the author has compiled a comprehensive vestibular evaluation battery for children, including RC subtests, CDP subtests (SOT and MCT), and VEMPs.

Since the vestibular system continues to mature through adolescence, the investigator has examined differences between two age groups of children. The first is a preschool/early school-aged sample from three through six years of age (N = 30), meeting the minimum weight of 40 pounds recommended for CDP research. The second sample of children (N = 30) fell within the preadolescent age range of 9 through 11 years. In addition to studying age effects between groups of children, the investigator also performed comparisons of pediatric results with clinically attained and published adult normative data. Since vestibular dysfunction is more common in hearing-impaired children and evaluation is crucial with this population, results of this study could provide important implications for application with at-risk populations.

The research questions for this study are as follows:

1. How efficiently may this test battery (RC, CDP, and VEMP) be utilized with the two groups of children, and what adaptations of adult techniques are necessary?
2. What implications might these findings with typically developing children have toward testing at-risk populations?
3. What maturational effects are observed with all measures between the two age groups of children?
4. What maturational effects are observed when comparing pediatric results with adult normative data?

METHODS

Two groups of normal-hearing subjects were utilized in this study. The first group was of preschool/early school age (three through six years), and the second group was preadolescent (9 through 11 years). With the younger group, the author insured that children met the minimum weight limit of 40 pounds recommended for CDP research. Thirty subjects were included within each age group, recruited via local preschools and public and private schools. Within the younger group were 16 females and 14 males, with a mean age of 5.5 years (SD = .9; range = 3.9–6.9 years). The older group consisted of 9 females and 21 males, with a mean age of 10.1 years (SD = .8; range = 9.0–11.8 years). Subjects had no history of vestibular disease and were not tested if suspected of middle ear or other otologic pathology via history or tympanometry. All subjects were asked to refrain from caffeinated beverages, aspirin, and over-the-counter cough and cold medications for 48 hours prior to testing, since these substances may affect vestibular test results. Subjects were asked to eat lightly prior to the testing session, in the event of queasiness or motion sickness.

Prior to undergoing the vestibular evaluation test battery, all subjects passed a pure-tone hearing screening at .5, 1, 2, and 4 kHz at 20 dB HL. *ASHA Guidelines for Audiometric Screening* (American Speech-Language-Hearing Association, 1992) were modified to include 500 Hz since screening was conducted within a double-walled IAC (Industrial Acoustics Co., Niederkruchten, Germany) sound suite. This screening was performed using a GSI-16, two-channel diagnostic audiometer (Grason-Stadler Inc., Madison, WI). Children also underwent and passed an immittance screening, utilizing the GSI-33 otoadmittance audiometer, to rule out the presence of middle ear dysfunction.

The following vestibular measures were utilized to compare the two groups' performance. Counter-balancing was implemented with respect to the order in which tests (RC, CDP, and VEMP) were performed, and all testing was performed by the author.

Rotary Chair (RC) Testing

All children were tested with the Micromedical 2000 Computerized Rotary Chair (RC) equipment (Micromedical Technologies, Chatham, IL), encapsulated within a darkened enclosure. Either adult or pediatric-sized goggles were utilized for VOG, depending upon head size/comfort. The child was seated on a parent's lap if she or he could not be tested alone. Rotary chair subtests were completed at .08 and .50 Hz. The examiner repeated subtests at .08 and .5 Hz during the same testing session and whenever attention span allowed, to collect data about test-retest reliability.

Step velocity (SV) measures were attained under clockwise (CW) and counterclockwise (CCW) conditions. With this test, the chair rotates at 100°/sec in one direction. As the chair begins to move, nystagmus is induced. A per-rotary time constant (TC) measure in seconds is obtained as the original slow component velocity (SCV) decays to 37% of its original strength. Nystagmus accelerates in the opposite direction as the chair suddenly stops (post-rotary condition). Computerized measures of the response decay, again in the form of a TC, are attained. With adults, the TC in returning the vestibular system to 37% of its original strength is approximately 13–14 sec and represents central prolongation of the peripheral signal (Goebel and Hanson, 1997).

Extensive tasking and mental alerting exercises, appropriate for the child's age, were implemented during all RC subtests, to minimize suppression of nystagmus. Nystagmic activity was recorded via the infrared VOG camera and observed on a television screen during all subtests. Measures of gain, phase (in degrees), and symmetry (in percent) were established per child for each VOR subtest, and TC measures (in seconds) were obtained for each SV subtest (two TC measures for CCW and two for CW rotation).

Computerized Dynamic Posturography (CDP)

The previously described six subtests of the SOT were performed, utilizing a Neurocom CDP System (Neurocom International, Clackamas, OR). During testing, the subject was secured via the smallest harness to prevent falling. Three 20 sec trials of the six subtests were completed whenever attention span and comfort would allow. Each child was extensively coached to maintain balance and positively reinforced throughout each subtest. The six SOT subtest scores were automatically calculated via computer for each subject.

The MCT subtest of CDP was performed with each subject. For MCT subtests, right and left latency scores were obtained for small, medium, and large platform translations in forward and backward directions. Latency is the time delay in milliseconds between the start of surface translation and the onset of active force exerted by the feet (Nashner, 2001). For all subjects, three trials were included with each of the subtests: small translation backward (baseline), medium translation backward, large translation backward, small translation forward (baseline), medium translation forward, and large translation forward. The amount of platform movement is directly proportional to subject height, according to standard CDP protocol. A latency reliability score from 0 to 4 is provided for the right and left side of the body with each of the six subtests, with "4" indicating the most reliable, "1" indicating the least, and "0" indicating no reportable/interpretable data. In accordance with Washington University's clinical protocol, data were included in this study only if the subtest reliability rating was 2 or higher.

Vestibular Evoked Myogenic Potentials (VEMP)

VEMP testing was performed for both right and left ears. Disposable electrodes (Nicolet, Inc., Madison, WI) were placed at specified locations on the head and neck: noninverting electrodes on each contracted SCM, inverting electrodes at each sterno-clavicular junction, and ground on the forehead. With adults, research has shown that the P1-N1 amplitude of the VEMP tracing is directly proportional to tonic level of neck muscle contraction (Lim et al, 1995; Murofushi et al, 1999). One method to standardize this level of contraction among patients has been to utilize commercially available EMG electrodes (also applied to the neck) and monitoring software. Adult patients have successfully been able to monitor level of neck contraction by maintaining a visual laptop target at a specified microvolt level (30–50). Results of a pilot study indicated that it was not feasible with children to utilize additional EMG electrodes on the SCM, for monitoring of tonic EMG activity. This was because of a child's limited attention span, limited space on a pediatric neck, weight of the EMG electrodes, and a child's difficulty in monitoring neck contraction to a desired target level.

The child was placed within a double-walled sound suite and asked to sit quietly,

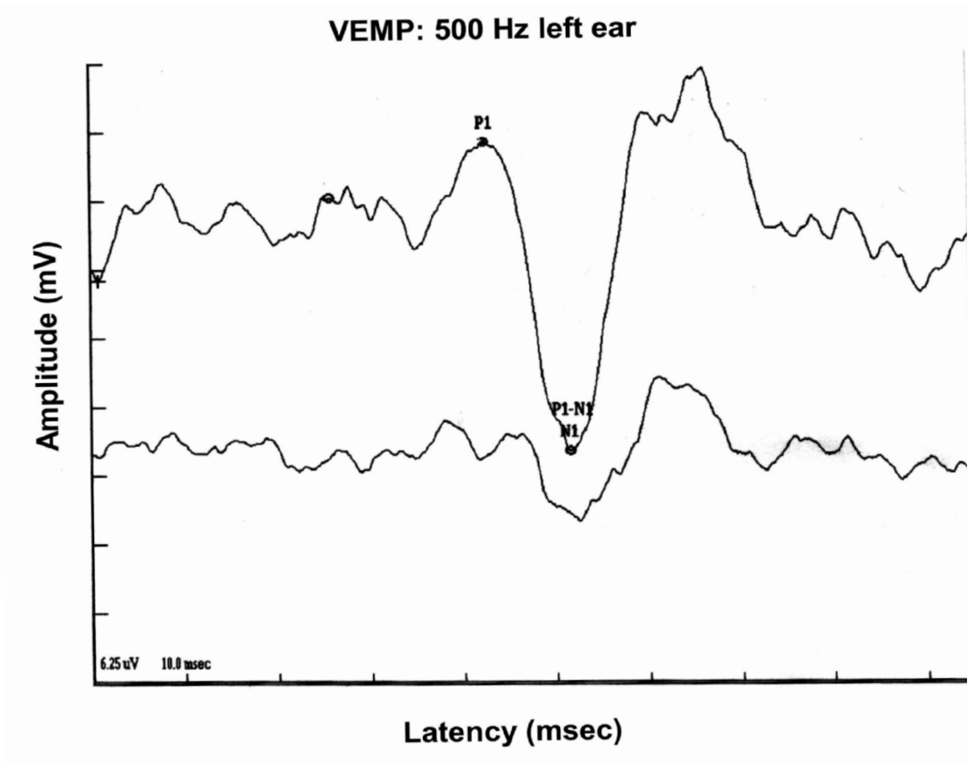


Figure 1. VEMP tracing for a six-year-old. Note P_1 and N_1 latencies, as well as P_1 –N_1 amplitude.

turning only the head to either the right or left for contraction of the neck muscles. The right ear was stimulated/ tested while the child turned the head to the left and vice versa. The child was asked to focus on a wall-placed cartoon character during testing to create the necessary muscle contraction. This designated spot was predetermined so that all children were seated at the same place with the head turned the same degree, toward the same cartoon character.

A Nicolet Bravo Evoked Potential unit (Nicolet, Inc., Madison, WI) was utilized for VEMP testing, using software version 3.00, and two-channel recording was attained. The VEMP procedure thoroughly described by Akin and Murnane (2000) was utilized in this study. The response was amplified (5000) and band-pass filtered from 20 to 1500 Hz with a 12 dB/octave slope. The epochs were 100 msec, including a 25 msec pre-stimulus baseline, and were digitized at 5 kHz. Stimulus levels for clicks (100 µsec, rarefaction) and 500 Hz tonebursts were calibrated in dB nHL by establishing the average behavioral thresholds for each stimulus using a group of normal-hearing adults. For 500 Hz tonebursts, stimulus presentation level was calibrated in dB peak SPL (120 dB SPL) using a Quest 1900 Precision Sound Pressure Level Meter with OB-300 1/3–1/1 Octave Filter Set, Quest 4140 $\frac{1}{2}''$ pressure microphone, and a Frye HA-1 2-cc calibrated coupler. ER 3A insert earphones delivered test stimuli.

A VEMP tracing was obtained for each ear, with click (95 dB nHL) and 500 Hz toneburst stimuli. This resulted in four tracings per child: click stimulus R, click stimulus L, 500 Hz toneburst R, and 500 Hz toneburst L. With toneburst stimuli, the examiner incorporated rarefaction onset phase, Blackman gating function, two cycle rise-fall time with no plateau. One hundred twenty eight sweeps were averaged per test. Counterbalancing was attained with right versus left ears and stimulus presentation (toneburst versus click). Test repetition to assess test-retest reliability was not always possible, due to limited attention span and comfort level of the child. Therefore, VEMP measures may approach more of a screening than diagnostic evaluation. P1 and N1 latency measures and P1-N1 amplitude measures were obtained from all present responses.

Figure 1 represents a typical VEMP waveform, obtained on a six-year-old subject. Attaining an accurate and repeatable P1-N1 amplitude was challenging since tonic level of neck contraction could not be monitored. Raw (uncorrected) amplitude measures were obtained for each tracing, with pre-stimulus baseline EMG activity calculated by hand. This baseline amplitude was calculated by averaging 50 amplitude values that occurred within the 25 msec pre-stimulus baseline period. A procedure was utilized whereby a normalized/corrected amplitude was obtained for each waveform by dividing the raw (uncorrected) amplitude by the average baseline measure (Li et al, 1999; Welgampola and Colebatch, 2001). It was felt that this procedure reduced variability and allowed for more accurate comparison of amplitudes.

DATA ANALYSIS

Prior to the major statistical analyses, all variables were examined to determine normalcy of distribution. Histograms, boxplots, and measures of skew and kurtosis were used. Most variables exhibited reasonably normal distributions, but some were noticeably skewed. To investigate the possible consequence of this skewness, transformations were performed on two different variables that appeared to demonstrate the greatest degree of skew: RC asymmetry at .08 Hz (cube root transformation) and a VEMP raw amplitude measure (fourth root transformation). Data analyses comparing age groups conducted on the original and the transformed data revealed no substantial differences in results. Therefore, the following results report analyses performed with the original, nontransformed data.

T-tests for independent samples were performed for all variables, to determine the presence of significant gender differences between male and female subjects. No consistent gender differences were noted, and each subject pool represents combined data for the male and female subjects. Where relevant, t-tests were also used to compare measures with "right" and "left" versions (e.g., VEMP). These analyses likewise did not reveal consistent differences, and thus right and left measures were averaged to yield more reliable composites.

Analyses of variance (ANOVA) were performed to determine age effects between groups of children. One-sample t-tests were implemented to determine significant differences between pediatric results and adult normative data. RC test-retest reliability measures were ascertained utilizing Pearson correlation coefficients. ANOVA was performed with SOT subtests with trials 1–3 serving as repeated measures, so that effects of trial and age group were seen. Relative generalizability coefficients were calculated for all conditions of the SOT test, to determine required number of trials for optimum reliability. ANOVA on VEMP data determined effects of ear-tested, test stimuli, and age differences. In the analyses that follow, degrees of freedom vary slightly due to occasional missing data for some measures. These rare instances arose because the test could not be adequately performed.

RESULTS

Rotary Chair Testing

Table 1 reports means and standard deviations for .08 and .5 Hz gain, asymmetry and phase measurements for the two groups. This table also compares these pediatric measures with adult normative data. The Washington University Dizziness and Balance Center contributed adult normative data supplied by Micromedical Technologies, and these contributions are included in software utilized for this study.

No significant age effects between the two groups of children were seen for gain, asymmetry, or phase measures at either frequency tested. When younger group data were compared with adult norms, the following pediatric results were within the normal range for adults: asymmetry at .08 Hz; gain, asymmetry, and phase at .5 Hz. A significantly higher gain measure at .08 Hz was seen for children, when compared to the adult upper limit of .65 ($t[28] = 2.65$; $p = .013$). A phase lead at .08 Hz was also seen for the younger age group, when compared with the adult

Table 1. Comparisons of Pediatric Means and Adult Normative Ranges (±2 sd) for RC: .08 and .50 Hz, with Standard Deviations Appearing in Parentheses

	.08 Hz			.50 Hz		
	Gain	Asymmetry (%)	Phase (degrees)	Gain	Asymmetry (%)	Phase (degrees)
	**		*			
Young	.72 (0.1)	5.41 (7.5)	9.45 (5..4)	.80 (0.1)	6.21 (9.5)	5.10 (3.9)
	**		*			
Old	.71 (0.1)	7.5 (4.6)	6.28 (5.6)	.77 (0.1)	4.86 (3.4)	6.76 (5.3)
Adult	.5 to .65	-15 to 15	-13 to 3	.5 to .88	-15 to 15	-5.2 to 15

*p < .01 **p < .05

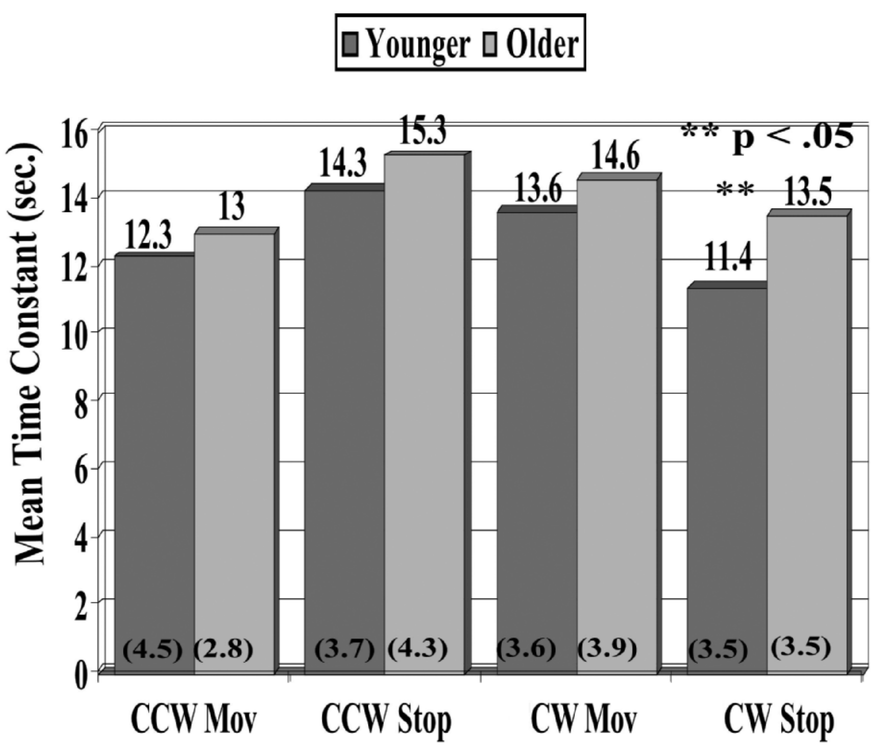
Table 2. Pearson Correlation Coefficients for Test-Retest of RC Gain, Asymmetry, and Phase Measures

Gain 1-2	Gain 1-3	Asymmetry 1-2	Asymmetry 1-3	Phase 1-2	Phase 1-3
.08 Hz					
.893*	.783*	.315	.372	.696*	.501*
.50 Hz					
.591*	.408**	.722*	.284	.312	.007

*p < .01 **p < .05

upper limit of three degrees (t[28] = .404; p < .01).

When older group data were compared with adult norms via one-sample t-tests, results mirrored those described above for younger child-adult comparisons. The following pediatric measures were within the normal range specified for adults:



Adult Normal Range: 5 – 25 seconds

Figure 2. Means and SDs (in parentheses) for SV time constants with CW and CCW rotation.

asymmetry at .08 Hz; gain, asymmetry, and phase at .5 Hz. A significantly higher gain measure at .08 Hz was seen for older children, when compared to the adult upper limit of .65 (t[28] = 2.50; p = .019). A phase lead at .08 Hz was also seen for the older age group, when compared with the adult upper limit of three degrees (t[28] = 3.13; p = .004). These results indicate greater differences at the lower frequency tested and help to suggest that adult norms should not be utilized when testing pediatric patients.

Test-retest reliability was explored for 13 subjects within the younger group and for 13 subjects within the older group for RC subtests at .08 Hz and .5 Hz. After initial testing, each child underwent a second and then a third trial of these subtests within the same two-hour testing session. Please see Table 2 for a summary of Pearson correlation coefficients for each set of measures. At .08 Hz, correlations were significant and strong for gain 1–gain 2, gain 1–gain 3, phase 1–phase 2, and phase 1–phase 3 comparisons. Correlations were not significant for asymmetry measures at .08 Hz. At .5 Hz, correlations were significant (but not strong) for gain 1–gain 2, gain 1–gain 3, and asymmetry 1–asymmetry 2. Correlations were not significant for asymmetry 1–asymmetry 3 or for phase measures.

These results indicate that gain measures appeared to be most reliable across frequency. Phase measures were reliable at the lower frequency, at least with this study and within a short time frame. Asymmetry measures appeared to be unreliable at .08 Hz but more reliable at the higher frequency, at least between test 1 and test 2. Phase measures appeared to be reliable at .08 Hz but not at .5 Hz.

SV testing proved to be a difficult task for children, especially within the younger group, due to head stabilization and/or

	EQUILIBRIUM			STRATEGY		
Conditions	Trial 1	Trial 2	Trial 3	Trial 1	Trial 2	Trial 3
1	89	91	94	99	99	99
2	93	88	89	99	99	99
3	93	91	84	99	99	99
4	47	31	20	88	87	84
5	67	40	46	89	84	90
6	7	32	36	40	89	89
	Composite = 55					

Figure 3. Example of displayed scores for six conditions of the SOT.

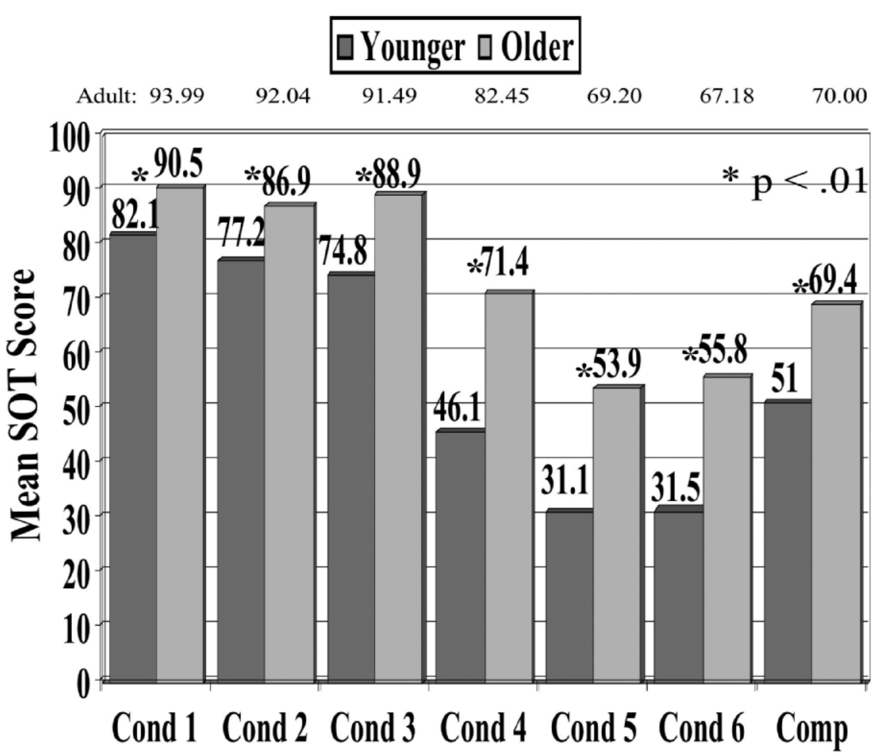


Figure 4. Mean SOT scores as a function of condition and age group.

tasking issues. Figure 2 contrasts mean CCW and CW time constants for each of the two groups. Within the younger group, data were interpretable from the following numbers of subjects: CCW per-rotary (moving): N = 16; CCW post-rotary (stop): N = 21; CW per-rotary (moving): N = 18; and CW post-rotary (stop): N = 20.

Within the older group, data were interpretable from the following numbers of subjects: CCW per-rotary (moving): N = 26; CCW post-rotary (stop): N = 29; CW per-rotary (moving): N = 27; and CW post-rotary (stop): N = 26. ANOVA revealed no significant differences between data obtained via clockwise and counterclockwise rotations. No significant differences were seen between the younger and older age groups for either decay measure with CCW rotation or for the per-rotary measure obtained via CW rotation. A significantly shorter TC was noted with the younger group, however, for the post-rotary measure obtained via CW rotation ($F[45] = 4.13$; $p = .048$). With so many statistical comparisons, it is not unusual for an occasional significant difference to occur by chance alone. This finding is most probably not clinically significant since all four time constant measures for each group fell within the adult normal range of 5–25 sec.

Table 3. T-Scores for Three Trials of Each of the Six SOT Conditions, When Comparing Scores of Younger Children with Adult Normative Data

	Condition 1			Condition 2			Condition 3		
Trials	1	2	3	1	2	3	1	2	3
t-score	-7.89	-6.73	-8.40	-5.21	-6.43	-7.19	-8.75	-6.66	-6.18
df	29	29	26	29	29	26	29	29	25
	Condition 1			Condition 2			Condition 3		
Trials	1	2	3	1	2	3	1	2	3
t-scores	-8.52	-8.92	-8.85	-9.44	-10.68	-9.18	-9.12	-7.55	-7.04
df	29	29	26	29	29	23	29	28	24

Note: $p < .001$ for all trials.

Table 4. T-Scores for Three Trials of Each of the Six SOT Conditions, When Comparing Scores of Older Children with Adult Normative Data

	Condition 1			Condition 2			Condition 3		
Trials	1	2	3	1	2	3	1	2	3
t-score	-3.58	-2.79	-3.22	-3.11	-3.77	-2.98	-2.38	-2.27	NS
df	30	30	27	29	29	25	29	29	
p	.001	.009	.003	.004	.001	.006	.024	.031	
	Condition 1			Condition 2			Condition 3		
Trials	1	2	3	1	2	3	1	2	3
t-scores	-4.58	-3.15	-2.49	-4.50	-4.18	-2.49	-2.84	-2.05	NS
df	30	30	28	29	29	26	29	29	
p	<.001	.004	.019	<.001	.001	.019	.008	.028	

Table 5. Motor Control Test (MCT) Latencies (msec) for Both Groups of Hearing Children, Contrasted with Adult Normative Data

	Small Forward	Medium Forward	Large Forward	Small Backward	Medium Backward	Large Backward
Younger	156.2	147.6	139.0	133.3	**129.1	*129.8
Older	146.0	140.8	**129.0	133.7	*131.2	120.2
Adult Norms		143	135		124	117

Note: Composites of right and left are represented.

$^{*}p < .01$ $^{**}p < .05$ when comparing children with adults

Computerized Dynamic Posturography

Figure 3 reports an example of scores recorded for the six conditions of the SOT. Strategy scores were not studied in this investigation. Mean composite scores were 51.0 (SD = 13.8) for the younger group and 69.4 (SD = 12.7) for the older group. Mean SOT scores for condition and age group are reported in Figure 4. Note that three trials are collapsed for each condition so that one grand mean is provided.

No significant differences among trials were seen for conditions 1–4 or for condition 6 with either age group. Significant differences were seen among trials for condition 5, one of the most difficult subtests where one relies on vestibular input alone, with both age groups. Improvement in scores with each age group appeared, possibly reflecting a practice effect. With mean data averaged across each trial, the ANOVA further revealed that the younger group of children achieved significantly lower scores than the older group on all six SOT conditions.

The following reliability coefficients were seen for the younger group for three trials each of conditions 1–6, respectively: .74, .74, .75, .86, .77, and .84. Many scientists typically strive toward a coefficient of .8 or higher with group data. These findings indicate that three trials may be optimum for conditions 4 and 6, although four trials might be optimal for conditions 1–3 and 5. Four trials may present a challenge for the attention span of such young patients.

The following coefficients were seen for the older group for three trials of conditions 1–6, respectively: .66, .72, .78, .89, .84, and .87. These results indicate that four or more trials might be optimal for conditions 1–3 (coefficients of .72, .77, and .80 for trials 4–6 of condition 1; .78 and .81 for trials 4–5 of condition 2; and .82 for trial 4 of condition 3), although limited attention span may also present a challenge with the older children. With regard to conditions 4–6, these findings indicate that only two trials per condition may provide the examiner with viable test results (coefficients of .84 for trial 2 of condition 4; .78 for trial 2 of condition 5; and .82 for trial 2 of condition 6).

A comparison of pediatric results with adult normative data was performed for all conditions of the SOT. Figure 4 compares pediatric SOT scores with adult normative

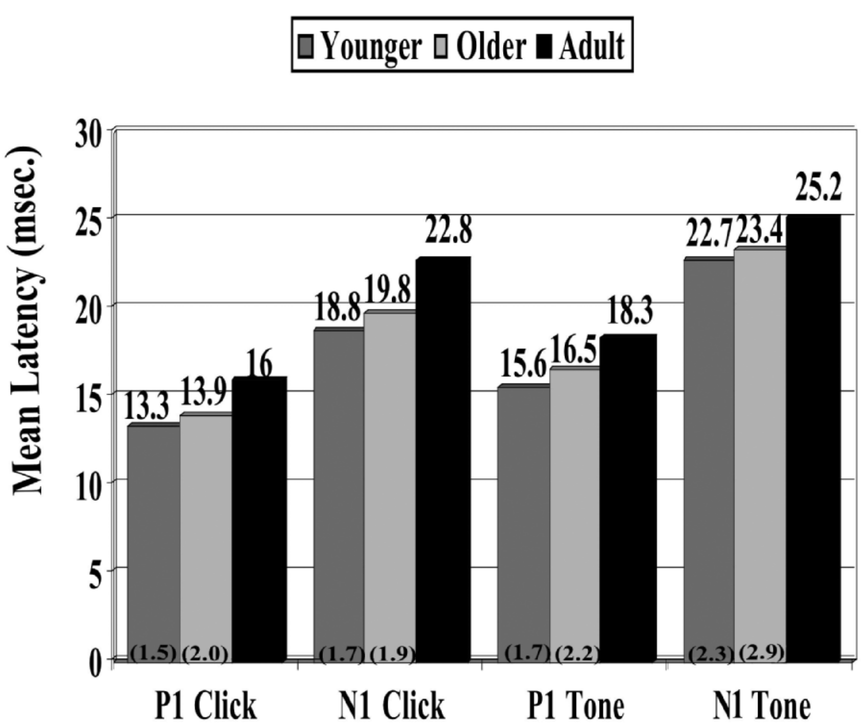


Figure 5. VEMP latencies as a function of age and stimulus.

Table 6. T-Scores Demonstrating Significant Differences between Pediatric VEMP Latencies and Adult Normative Data Obtained Utilizing the Same Procedures

	Click P1	Click N1	500 Hz P1	500 HzN1
Younger children and adult comparisons				
t-score	-12.19	-15.86	-10.49	-7.24
df	28	28	28	28
Older children and adult comparisons				
t-score	-6.29	-9.27	-6.36	-4.16
df	27	27	27	27

Note: All were significant at the p < .001 level.

data. For the younger group, significant deviations (lower scores) from adult norms were seen for all trials of all six SOT conditions. Table 3 reports t-scores for the younger group–adult norm comparisons, with each trial of the six SOT conditions. For the older group, significant deviations (lower scores) from adult norms were seen for all trials of all SOT conditions except with the third trials of conditions 3 and 6. Table 4 reports t-scores for the older group–adult norm comparisons, with each trial of the six SOT conditions.

Latency scores for the MCT are reported for each group in Table 5. Latency values of 200 msec or greater are generally considered within the abnormal range for adults, from a clinical perspective, and no child's performance exceeded this value. No significant differences were seen between age groups for small or medium translations in either a forward or backward direction. Latencies for the older group, however, were significantly shorter than those for the younger group with large translations in both forward and backward directions (F[1,56] = 8.81; p = .004; F[1,57] = 5.50; p = .023). While these are statistically significant differences, they may not be clinically significant in view of above-described normal range for adults.

Table 5 also compares pediatric MCT

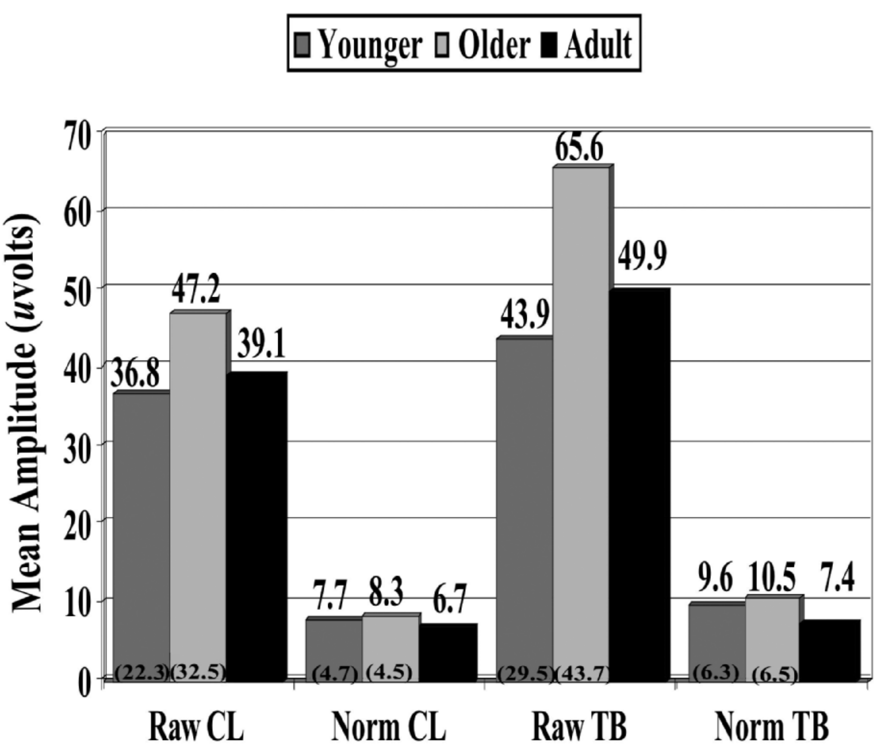


Figure 6. VEMP amplitude as a function of age and stimulus.

results with adult norms. Adult normative data were available from Neurocom, Inc., for medium and large translations, but not for small translations (considered a baseline). With the younger group, significantly longer latencies were noted for medium ($t[28] = 2.08$; $p = .047$) and large ($t[28] = 5.26$; $p < .001$) backward translations but not with forward translations. With the older group, significantly longer latencies were seen for medium backward ($t[29] = 4.04$; $p < .001$) translations. Interestingly, significantly shorter latencies were noted for large forward ($t[29] = -2.37$; $p = .024$) translations.

Vestibular Evoked Myogenic Potentials

Salient features of each VEMP tracing are P1 and N1 latency, uncorrected P1-N1 amplitude, and corrected (normalized) P1-N1 amplitude. The corrected amplitude is the important amplitude variable with this study. Figure 5 compares P1 and N1 latencies as a function of age group, while Figure 6 compares amplitudes as a function of age group. Adult normative data for VEMP were obtained with the same evoked potential equipment and same procedures previously described for collecting child data.

Significant stimulus effects were seen between click and 500 Hz stimuli with both age groups, consistent with published studies utilizing adult subjects (Akin and Murnane, 2000). P1 latencies appeared later for 500 Hz than click stimuli for both right and left ears ($F[1,50] = 155.38$; $p < .001$; $F[1,54] = 168.60$; $p < .001$). Similarly, N1 latencies appeared later for 500 Hz than for click stimuli with both right and left ears ($F[1,50] = 128.30$; $p < .001$; $F[1,54] = 239.60$, $p < .001$). A significant difference between stimulus type was also seen with normalized amplitude measures. Tracings obtained via 500 toneburst stimuli demonstrated a significantly higher amplitude for right and left sides ($F[1,50] = 5.13$; $p = .028$; $F[1,54] = 7.63$; $p = .008$).

Significant differences were noted between child latencies (both groups) and clinic adult normative values. When results obtained from the younger group were analyzed, latencies of both P1 and N1 appeared earlier than they appeared with adults, for both click and 500 Hz toneburst stimuli. When results obtained from the older group were analyzed, results mirrored the above, and latencies of both P1 and N1 appeared sooner than they appeared with adults for both types of stimuli. Table 6 reports t-scores for child-adult comparisons as a function of stimulus and latency measures.

These findings suggest that VEMP latencies may vary as a function of age and that child latencies appear sooner, at least with regard to procedures and equipment utilized in this study. Comparisons were made between pediatric normalized amplitude measures and adult normative data, utilizing the same equipment and procedures. No significant differences were seen between adults and children of either group, with toneburst or click stimuli. Considerable intersubject variability was noted with pediatric VEMP testing, in addition to variability between ears of the same subject. This variability, especially with child subjects, may be partially due to such factors as level of tonic neck contraction, movement during the test session, fatigue, and electrode impedance. Because of such extensive variability, amplitude ratio values (between right and left ears) were not attained as they sometimes are with adult patients.

DISCUSSION

The results from this study demonstrate that the described, comprehensive vestibular test battery may successfully be performed with children of the selected age ranges. No significant age effects between the two groups of normal-hearing children were noted with gain, asymmetry, or phase measures for either RC test frequency. When compared with adult norms, there were no significant differences between child and adult asymmetry measures for either frequency, or for gain and phase at .5 Hz. Gain measures attained for each group of children revealed significantly higher measures at .08 Hz, however, than the upper limit of adult normal range. In addition, a significant difference was seen with the phase measure (child phase lead) at .08 Hz for both groups. These findings indicate the importance of testing several test frequencies when performing RC testing (as did Staller et al, 1986) and the importance of utilizing child normative data with pediatric patients. It has been important to attain further child normative data related to gain, asymmetry, phase, and step velocity measures of RC with comparisons to adult normative data.

Test-retest reliability was examined for RC measures at both test frequencies, revealing that the gain measure was very reliable at both test frequencies. Phase was reliable at .08 Hz but not as reliable at .5 Hz within this study. Asymmetry appeared reliable between test 1 and test 2 for the higher frequency but not for the lower frequency tested.

SV measures were difficult to attain, especially with the younger children. This task may have been too difficult in light of tasking and/or head control issues. No significant age effects were seen between the two groups of normal children with respect to either CCW rotation or with the per-rotary CW measure. An age effect was seen, however, with the CW post-rotary measure, in that the younger group demonstrated a significantly lower time constant than the older group. Wide variability was seen with both groups, and it is not readily apparent why there was a significant difference between groups with this one measure only. This was the last RC measure obtained, and fatigue could have played a role, particularly with the younger children. With such a large number of significance tests being conducted, it would not be unusual for a few results to show significant differences by chance alone. This effect is just below $p = .05$ and is not considered a strong effect.

There appeared to be no significant differences between pediatric results of either group and established adult normative data. That is, all four time constants for both groups of children appeared within the adult normal range. Because of this, the effect described above is most probably not clinically significant.

Out of 61 subjects recruited, only one could not adapt tasks required for RC, and only two required the testing to be performed while sitting on a parent's lap. Most children felt that this test was enjoyable, resembling an amusement park ride. Pediatric goggles with video camera attached efficiently recorded the children's eye movements.

The console talk-back system was utilized constantly for encouragement of tasking exercises and for continual positive reinforcement. Oftentimes, it was necessary to open the door between subtests and to reinstruct and encourage, given the limited attention span of some children. In addition to limited attention span, challenges involved children keeping the eyes open and the head within the proper position.

With respect to SOT subtests of CDP, it was found that older children performed significantly better than younger on all six subtests. These findings may be consistent with a maturational effect of the vestibular system as the child matures from preschool through school age, and are consistent with maturational effects reported in the literature (Hirabayashi and Iwasaki, 1995). When younger children's results were compared with adult normative data, significantly poorer pediatric scores were seen for all trials of all SOT conditions. Significantly poorer scores were also seen when older children's results were compared with adult norms. These findings again might suggest maturational effects, from preadolescence to adulthood, as also reported by Shimizu et al (1994).

Statistical analysis provided further insight as to optimal number of SOT trials required for reliable measurement. With the younger group, four seemed to be optimal with conditions 1–3, while three trials appeared sufficient for conditions 4–6. Four or more appeared optimal with the older group for conditions 1–3, although the above recommendations may not be feasible when working with the limited attention span of children. Fortunately, two trials seemed to be sufficient for conditions 4–6 when testing the older children.

With respect to the MCT, older children displayed significantly shorter latencies than younger children with large translations in both forward and backward directions. Child data in both age groups differed significantly from adult normative data. The younger group displayed significantly longer latency values than adults with medium and large backward movements but not with forward movements. The older group displayed significantly longer latency values than adults with medium backward movements and significantly shorter latencies (better performance) with large forward perturbations.

All SOT and MCT subtests may successfully be performed with children of the age ranges studied in this investigation. The smallest jacket or harness was utilized for testing subjects, and subjects readily adapted to all tasks required. Continual reinforcement and encouragement to maintain balance was provided during each trial of each subtest. The children were also continually reminded that the harness and the examiner's presence would keep them from falling.

This study may be viewed as contributing normative child data related to the various tests implemented. A few studies have reported norms for SOT, and one of the most notable is Hirabayashi and Iwasaki (1995) because of their relatively larger number of subjects. The current investigation supplements these norms and also contributes normative data for the MCT.

With regard to VEMP, no significant age effects between the two groups of children were seen with either P1 or N1 latencies. Current research is focusing on latency differences as a function of age, although most studies have leaned toward studying advancing age. Child latencies found in the present investigation appear to be in close agreement with adult latencies appearing in the literature (Colebatch and Halmagyi, 1992; Akin and Murnane, 2000). When comparing child latencies with adult norms attained on the Nicolet Bravo unit used for the current study and utilizing the same procedures, child latencies were found to appear significantly sooner. These findings are in good agreement with the earlier pediatric latencies reported by Kelsch et al (2006). The adult latencies obtained with the Bravo unit may be more delayed than some published norms appearing in the literature (Colebatch and Halmagyi, 1992; Halmagyi and Colebatch, 1995; Akin and Murnane, 2000), and the reason for this is not known. This underscores the importance of obtaining individual normative data within each clinic and replicating, to account for possible equipment and procedural differences, as well as the importance of additional research studies to explore effects of age on the VEMP. VEMP latency and intensity values have not abundantly appeared in the literature related to pediatric populations, and it is important to study these values as a function of age.

The VEMP measure is important because it lends information about saccular function and status of the inferior branch of the vestibular nerve. Because of the high incidence of vestibular dysfunction with children demonstrating hearing impairment and other childhood disorders, it may be important to consider performing VEMP along with other vestibular measures at the earliest possible age. As found with adults (Akin and Murnane, 2000), significant stimulus effects were seen with P1 and N1 latencies. Both P1 and N1 latencies appeared later in time with use of a 500 Hz toneburst stimulus than with a click stimulus.

Comparisons of normalized amplitudes for both groups of child subjects revealed no significant age effects between groups, although wide intersubject and interaural variability was seen. Because of the wide variability, asymmetry ratios (comparing right and left ears, as is oftentimes conducted with adults) and other comparative ear measurements were not calculated. The challenges of performing VEMP with children lend support toward future reliability studies. VEMP normalized amplitudes were significantly higher for both groups of children with the 500 Hz tonebursts, as opposed to clicks. No significant age effects were seen with normalized amplitudes when comparisons of child data and adult normative data were made.

VEMPs may easily be performed on children within the age groups included in this study. It is a rapid, objective, and noninvasive measure. Obtaining of each VEMP tracing was swift, since it only requires 128 or fewer sweeps. Because of limited attention spans and the exposure to high-intensity stimuli, however, it was not always possible to repeat each tracing to insure reliability. This would be a clinical recommendation and possible focus for future study.

CLINICAL APPLICATIONS AND SUGGESTIONS FOR FUTURE RESEARCH

The three vestibular tests used in this study comprise a battery that assesses major components of the vestibular system. One of the author's purposes was to help determine feasible pediatric protocols for each individual test.

RC testing should be performed at several frequencies, especially when low gain is attained with one test frequency. The current protocol of testing at .08 and .5 Hz was successful, and child subjects tolerated it well. SV measures were tolerated well, although results were sometimes difficult to measure and interpret, especially with the younger subject group. Testing procedures might be improved by enhancing measures to stabilize the head and implementing more childlike tasking techniques (nursery rhymes and music, for example). As Cyr and colleagues advocated (1983), these RC measures may be more of a screening tool with very young children, and it is crucial to observe presence or absence of nystagmic activity via video camera. The gain measure appears reliable from test to retest, but reliability of phase and asymmetry might be questionable. Sitting on a parent lap is a very viable option for RC testing with young children, with many finding it enjoyable. Measurement of gain, asymmetry, phase and TC parameters, as well as observing nystagmus on a monitor are viable tools in assessing VOR function. RC may provide a milder stimulation and information about more harmonic acceleration frequencies than bithermal caloric irrigations. Additional investigations may study younger populations, enhanced head stabilization techniques, and additional test frequencies.

CDP was also efficiently utilized in this study to measure functional balance. Three trials of all six SOT subtests were employed, to facilitate comparison with adult norms. Even though each trial lasted 20 sec, the attention span of even the older children was taxed with three trials. Since most children performed well on conditions 1 and 2, it might be possible to perform only conditions 3–6 for diagnostic information. The clinician might perform more difficult conditions first, adding easier conditions if attention span allows. The order in which tests are performed might be a topic for further study. Analyses of the data revealed that the third trial of each subtest optimally was necessary for reliability, whenever possible. Two trials per condition would most probably suffice with older children when testing conditions 4–6.

The MCT provides latency values as the child attempts to regain balance in response to small, medium, and large translations in backward and forward directions. There did not appear to be attention span difficulties, since the test is quite time efficient.

Questions related to the most efficient CDP test battery with younger and younger populations might be explored in addition to CDP results with various childhood disorders. SOT and MCT were the only subtests studied with this project, and additional child studies are recommended, incorporating the adaptation test and other CDP subtests. It would be an interesting contribution to the literature to compare strategies that children use to maintain balance with strategies that adults use.

VEMP may also be a viable diagnostic procedure for children, specifically for assessment of saccular function. This procedure was found to be time efficient, noninvasive, and objective for use with the studied age ranges of children. It is recommended that the clinician incorporate at least two repeated measures per stimulus per ear. Well-formed, interpretable VEMP tracings were attained via both 500 Hz toneburst and click stimuli; therefore, the utilization of both may be redundant. The 500 Hz toneburst stimulus might be the stimulus of choice, since amplitude measures were more robust than with click stimuli.

It appeared that interpretable VEMP tracings may be obtained with only 64 sweeps per tracing, which would diminish concerns related to attention span with children. Although not performed with this study, bilateral tracings may also be effective with children. With this type of testing, the child would recline and elevate the head to contract the neck muscles. Inserts would deliver stimuli to both ears simultaneously and potentials would be recorded from both SCMs simultaneously.

Monitoring of tonic EMG activity was not effective with these age groups of children, as the electrodes were too heavy and there was insufficient room on each SCM for three electrodes. Monitoring neck contraction to reach a certain target level on a laptop computer graph also appeared too difficult for the age groups used in the present study. Equipment and software for such monitoring could be a recommendation for future pediatric VEMP testing.

Future studies may determine feasibility of measuring VEMP thresholds in children. The procedures outlined in this study may describe more of a screening, as opposed to diagnostic, procedure in young children. That is, the clinician might be viewing presence or absence of the VEMP tracing with latencies also providing valuable information. More research may be needed related to interpreting VEMP parameters with respect to varying degrees of saccular and/or inferior vestibular nerve damage. Additional studies might explore effects of stimulus parameters on the pediatric VEMP tracing: frequency of toneburst, duration of stimuli, and others. Child studies might explore VEMP diagnostic results expected with various childhood disorders. Investigators might study optimum electrode placement and whether it indeed is the SCM in children, the bone-conducted VEMP, and other issues that are being explored with adult subjects. Crucial VEMP parameters for interpretation appear to be P1 and N1 latencies, P1-N1 amplitudes, and the VEMP thresholds. Additional studies might focus on latencies with other age groups and with utilization of other stimuli.

Clinical recommendations may also be in order beyond the realm of the described battery. As with any patient with balance disorders, a thorough case history is one of the most important diagnostic tools. Dizziness questionnaires for children are not currently prevalent, although their development would be highly beneficial. Bithermal caloric irrigation and other aspects of VOG is a highly effective tool with adults and should also be considered with children. In the author's experience, VOG may be successfully performed on children within the older age range and possibly may be performed on cooperative children as young as six to seven years. Oculomotor subtests may be modified for children, as previously described, and may be beneficial in assessment of central pathology. For the sake of thoroughness, any child who presents with a possible balance disorder should undergo comprehensive otolaryngologic and audiologic evaluations.

There remains a paucity of research and clinical work related to balance disorders in children. Among the primary messages conveyed with this study is that vestibular function can and should be tested with many children. In reviewing the literature, the professional community may note that vestibular dysfunction has been linked to a myriad of childhood disorders. Additional studies to explore these relationships would be beneficial. Further research should explore effective testing techniques for use with younger and younger populations. Multidisciplinary research and clinical work to improve correlations among diagnostic tools or to determine how they complement one another would serve to enhance patient care. Collaboration and sharing of knowledge across disciplines should be implemented.

A thorough discussion of vestibular evaluation in children leads to the issue of remediation. Vestibular rehabilitation has rapidly taken hold within the adult arena and is certainly an area where more research is needed with children. Adult dizzy patients may be referred for head and neck exercises, learning visual compensation strategies, relying more on ankle versus hip strategies, or a wide range of other procedures. Just as a multidisciplinary approach may be recommended with diagnostics, the involvement of numerous disciplines might also be effective with treatment. Occupational and physical therapy colleagues are already working with children who demonstrate delayed motor performance, balance issues, and difficulty with head and postural control. Additional studies are warranted with respect to the various childhood disorders that accompany balance dysfunction and the most effective ways to remediate.

The current study has served to highlight the need for additional research and clinical work in the area of vestibular disorders in children. Vestibular dysfunction may accompany a myriad of childhood disorders, when hearing loss is or is not present. Methodologies must be fine-tuned, particularly with younger and younger children and results related to childhood disorders. This investigation has described several tests that may efficiently be performed with young children. The suggested test battery presented within this study appears to successfully evaluate major aspects of the balance system and is well tolerated by pediatric populations. Results obtained with pediatric patients may not always effectively be compared to adult norms. This study has served to demonstrate maturational effects and to add to the normative data banks for children. Audiovestibular health-care professionals must not lose sight of the high incidence of balance disorders and of the importance of evaluation with young children. As professionals work to develop more efficient diagnostic tools and more effective remediation strategies, it is important to strive toward earlier and earlier identification. The earlier a vestibular disorder is identified, the sooner the implementation of remediation strategies may begin if warranted.

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