Adaptation of adult techniques for evaluating vestibular function in children

By L. Maureen Valente

In the 1980s, I had the honor of working with Dr. David Cyr at Boys Town National Research Institute in the area of pediatric vestibular evaluation. We adapted adult techniques for pediatric patients through such strategies as painting our rotary chair enclosure to resemble a spaceship, seating the child on a parent's lap, placing an infrared camera in front of the child's eyes to record nystagmic activity, and piping in familiar nursery rhymes for tasking purposes. Using these methods, we accomplished our goal of obtaining sound clinical data, although perhaps the largest challenge we faced was encouraging parents to hold little arms so electrodes weren't removed as rapidly as we could paste them onto little faces.

Dr. Cyr's passing left a void in our profession in view of his many important contributions in the area of vestibular evaluation of the pediatric patient. It made sense 5 years ago, when I was conducting research for my own doctoral dissertation topic, to return to these roots and attempt to help devise further tests and answer unanswered questions. A literature review revealed a paucity of research in this area, and conversations with colleagues around the country underscored the great clinical need for further development.

A REVIEW OF THE LITERATURE

As I conducted my review, two distinct bodies of literature emerged. One of these encompassed studies performed by our colleagues in occupational and physical therapy (OT and PT). I read many fascinating articles discussing diagnostic procedures, many of which fall within these professionals' scopes of practice but may seem rather foreign to the practice of audiology. Vestibular dysfunction has been linked to such disorders as autism, motor delay, learning disability, and dyslexia.1-9

The second, more familiar, body of literature comprised studies in audiology and otolaryngology. These could be further divided into vestibular disorders that accompany hearing loss and those that do not. I found studies that related vestibular dysfunction to sensorineural hearing loss, otitis media, benign vertigo of childhood, migraine, and various other childhood syndromes of a genetic nature.8,10-18 My impression was that there was very little existing literature and little overlap between these bodies of studies.

Audiology has emphasized early identification of hearing impairment so that early intervention may be implemented. If a vestibular disorder exists in a young child, early identification also may be important in many instances. However, our profession has traditionally encountered challenges in finding tests that are efficient and appropriate for use with the pediatric population. An audiologist performing vestibular evaluation with children must become familiar with development of the vestibular system and maturational effects upon test results. Valente summarized a review of the literature with regard to the effects of age on nystagmic response following per-rotary and caloric stimulation.19

Among recurring threads in our literature is that the clinician must obtain pediatric normative data and that pediatric evaluation results should not be compared with adult normative data. Valente studied two age groups of typically developing children to supplement existing normative data banks and to explore maturational effects.20 In addition to differences among pre-school and pre-adolescent children with regard to rotary chair (RC) and computerized dynamic posturography (CDP) measures, these studies uncovered further differences between child and adult populations with these tests and with vestibular evoked myogenic potentials (VEMPs).

A second recurring thread is that adult techniques must be modified for use with pediatric patients. Traditionally, audiologists have used electro-oculography (EOG) or video-oculography (VOG) for evaluation of the vestibular system. Many have regarded one of the subtests, bithermal caloric irrigation, as one of the gold standards for evaluating the vestibulo-ocular reflex (VOR) and the horizontal semi-circular canal (SCC) function. However, any audiologist who has attempted these measures with children knows the difficulties that may arise when asking a child to place head and body into various positions or when irrigating ear canals with warm and/or cool water or air to stimulate the
vestibular system. In my experience, these tests often may not be conducted effectively until a child is at least 5 to 7 years of age, which means they are of little use in achieving what may reasonably be described as “early identification.”

**ADAPTING METHODS FOR CHILDREN**

The advent of computerized technology brought with it many innovative measures for evaluating the vestibular system in adults, and many of these measures may be adapted for children. As noted above, Cyr adapted many adult electronystagmography (ENG) and RC techniques for children.\(^1^\)\(^2^\)\(^-^\)\(^4^\) Additional adaptations included using cartoon characters for calibration and oculo-motor testing such as optokinetic (OPK), visual pursuit, and saccades. Caloric irrigation with air may be recommended over water with children, as may simultaneous as opposed to sequential irrigations. With RC testing, it may be impossible to complete the full sinusoidal harmonic acceleration (SHA) battery because of the child’s limited attention span.

Based upon previous studies, Valente investigated RC results at .08 Hz and .5 Hz with two age groups of children.\(^1^\)\(^9^\) Reliable measures of gain, phase, and symmetry may be obtained with adaptation of techniques, such as seating the child on a parent’s lap, using pediatric goggles to record eye movement, continual positive reinforcement, tasking measures appropriate for a child, and enclosure opening between subtests. It is important to test more than one test frequency because of the non-linearity of the vestibular system across frequency. It is also crucial to verify results by observing nystagmic activity via television monitor. Step velocity (SV) testing may also be performed with children and time constants may be obtained, although head stabilization with children continues to be challenging.

Studies also exist in the literature and there are normative data related to some subtests of CDP. Perhaps the most widely used subtest is the Sensory Organization Test (SOT), in which various conditions involve removing or compromising proprioceptive and/or visual cues. Of particular interest to the clinician are Conditions 5 (eyes closed and platform sway-referenced) and 6 (visual surround and platform sway-referenced), where the patient relies on vestibular cues alone. Rine et al. found that this test may be successfully performed with children as young as 3 years, and they helped delineate performance as a function of age.\(^2\)\(^5^\)

In studying the two age groups of children, Valente found that the younger group performed significantly more poorly in all conditions than did the older group and that all children (including those aged 9 to 11 years) performed significantly more poorly than the adult normative data.\(^1^\)\(^9^\) She also found that the Motor Control Test (MCT), another CDP subtest, may be successfully performed with children, and her findings were added to pediatric normative data banks.

Shekholeslami measured VEMPs on typically developing and at-risk infants, finding that the procedure may be performed on this population and that wave morphology is similar to that of adult subjects.\(^2\)\(^7^\) Kelsch measured VEMPs in two age groups of children and found that peak latencies may arrive earlier than those measured with adult tracings.\(^2\)\(^8^\) Valente also performed click and 500-Hz tone 7 burst-evoked VEMPs on children in two age groups, and found no significant differences in latency or amplitude measures between groups.\(^2\)\(^9^\) However, she found that latency appeared sooner with children when she compared these results to her own adult normative data. Interestingly, her pediatric findings were in agreement with adult normative data collected by some other investigators.\(^2\)\(^9^\) This served as a reminder of the importance of collecting normative data in one’s own clinic, using standardized procedures, and replicating one’s findings.

My conclusions are that VEMP measures may be performed successfully with children, although this test appears to be more daunting with them than RC or CDP. VEMP amplitude measures are difficult to interpret in that they are directly related to level of SCM contraction and also to stimulus intensity. Some clinicians have met this challenge with adults by target monitoring of EMG activity involving additional electrodes.\(^2\)\(^9^\) In a pilot study, I found this extra electrode procedure very difficult with pediatric patients because of their small necks, but it is possible to calculate asymmetry ratios or normalized amplitude from raw amplitude measures.

Other VEMP adaptations include seating the child on a parent’s lap, focusing on a cartoon character to maintain head turn for muscle contraction, using 500 Hz rather than click stimuli for a more robust waveform, continual positive reinforcement, positioning the child for bilateral/simultaneous recording, and receiving a “fun sticker” upon removal of electrode stickers.

It is essential for professionals to work…

At the time of the study, the equipment manufacturer recommended that children under 40 pounds not be tested for research purposes. Pediatric adaptations for CDP include using the smallest harness, providing continual explanation and positive reinforcement, measuring height to correspond to the extent of MCT platform perturbations, possibly foregoing three trials of each condition if attention span is limited, making certain that the visual surround is child-pleasing, and providing a tangible reward following each trial.

Vestibular evoked myogenic potentials (VEMPs) have come into wide clinical use with adults over the past decade. Electrodes attached to the contracted sternocleidomastoid (SCM) muscle help record an electrical potential generated from the saccule when auditory stimuli are presented.\(^2\)\(^6^\) The quick, easy, and non-invasive nature of this procedure has led to some clinical work and a few studies with pediatric subjects.

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as a team and for us to continue working toward efficient test techniques for all age groups, including younger and younger children. Many of our existing methodologies measure horizontal SCC function, and it is important to continue finding ways to measure other components of the vestibular system. One reason that VEMP testing has been so well received is that it is one of the few measures that help assess otolith, as opposed to SCC, function. When clinicians adapt adult techniques for children and establish pediatric normative data, it is also important for them to assess the efficiency of their testing techniques with children who are at risk for vestibular function.

My interest in this area stems from serving as director of audiology studies in a large medical school and being housed in close proximity to several oral schools for hearing-impaired children. Coming into contact with many hearing-impaired children who either wear hearing aids or are cochlear implant recipients has led me to consider that some may be in need of vestibular evaluation. Simply put, the disease process or other entity that has affected their hearing status may very well have affected their vestibular function as well.

For this reason, I recruited a sample of hearing-impaired children from our large metropolitan area in the same age ranges as the typically developing children previously described. The RC, CDP, and VEMP procedures described above may be efficiently used with this population, with perhaps additional adaptation of techniques. Most of the nine children recruited did demonstrate some type of difficulty, from very subtle to great. Here are three of these case studies.

**THREE CASE STUDIES**

**Case 1**
The first subject is a female in the younger age group (3 through 6 years). Upon recent audiologic evaluation, her audiologist observed no measurable response at the limits of the equipment for the right ear from 250 to 4000 Hz. In the left ear, a profound hearing loss was seen at 250 and 500 Hz, with no responses found at higher frequencies. Etiology of the hearing loss is unknown, as is acquired versus congenital status. The child has worn a cochlear implant in the right ear for several years.

Immeasurably low RC gain was seen at .08 Hz and, therefore, we could not interpret additional measurements of phase or symmetry at this test frequency. When testing at .5 Hz, the following measures were noted: gain of .76; asymmetry of 7%; and phase of 4 degrees. These findings indicate vestibular hypoactivity at the very lowest frequency tested, while measures were within normal limits at a higher frequency of .5 Hz. Step velocity (SV) measures were attempted but could not be interpreted, consistent with absence of nystagmic activity observed upon chair rotation.

When Sensory Organization Test (SOT) Conditions 1 and 2 are compared, diminished scores may be seen when the patient’s eyes were closed, even though the platform was stable. A fall was seen initially with the first trial of Condition 3, when the visual surround was sway-referenced, but subsequent scores substantially improved. A fall was seen on the initial trial of Condition 4 where the platform was sway-referenced. Condition 5 scores yielded better performance than Condition 4, even though the child’s eyes were closed with the former. Condition 5 scores indicate that this child is experiencing difficulty maintaining balance, especially when proprioceptive and/or visual cues are compromised. This is verified in Condition 6 where falls were seen with trials 1 and 2. MCT latencies for forward translations were unusually prolonged.

No VEMP response could be attained for the implanted right ear, using either the click stimulus or the 500-Hz tone-burst stimulus. VEMP tracings were noted for the left ear as shown in Table 1. These results appear to be consistent with results obtained with hearing children.

The mother reported that the child experienced difficulty with a few gross motor areas. Specifically, she was not yet able to do a forward somersault or ride a bicycle with or without training wheels. The child exhibits some vestibular dysfunction that is concomitant with her profound, sensorineural hearing impairment.

| Case 1 | :
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<tr>
<td>P1 latency</td>
<td>N1 latency</td>
<td>Normalized amplitude</td>
</tr>
<tr>
<td>Click</td>
<td>13.1 msec.</td>
<td>21.10 msec.</td>
</tr>
<tr>
<td>500 Hz</td>
<td>15.9 msec.</td>
<td>21.10 msec.</td>
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Abnormal findings (hypoactivity) were seen with the RC lowest frequency and nystagmic activity could not be elicited upon chair rotation until a higher frequency of rotation was implemented. With CDP, falls and lowered scores were encountered when visual cues were compromised and when the child relied solely on vestibular input. Motor control latencies on some subtests appeared delayed. Although VEMPs could be elicited and parameters appeared within normal limits for the left ear, these tracings could not be attained for the right, implanted ear.

**Case 2**
The second case involves a male who was also recruited within the younger age group. Etiology of his hearing loss is genetic, although it wasn’t detected for several years. Audiometrically, this child demonstrates a moderate to severe, symmetrical, and gradually sloping sensorineural hearing loss. He has successfully worn binaural amplification since his hearing loss was identified.

We found the following measures when testing RC at .08 Hz: gain of .76, asymmetry of 8%, and phase of 8 degrees. When testing at a higher frequency of .5 Hz, the following measures were noted: gain of .89, asymmetry of 1%, and phase of 2 degrees. Robust nystagmic activity was noted during both subtests, and these findings indicate normal gain, asymmetry, and phase measures when compared with child and adult norms. SV measures revealed the following time constants: 9 seconds (per-rotary) and 8 seconds (post-rotary) with CW rotation and 11 seconds (per-rotary) and 8 seconds (post-rotary) with CCW rotation. These findings appear to be grossly within normal limits and robust nystagmic beats were again noted via chair rotation.

The child’s limited attention span allowed only two trials to be completed for each SOT subtest. Results for Conditions 1 and 2 showed good scores with eyes open and eyes closed and when the
When viewing SOT Conditions 1 and 2, one may note comparable scores with eyes open and eyes closed when the platform was stable. A slightly diminished score was noted on the first trial of Condition 3, when the visual surround was sway-referenced, but subsequent scores improved substantially. An even lower score was seen on the first trial of Condition 4 when the platform was sway-referenced. Even though the child’s eyes remained open under this condition, substantially decreased performance was noted with each subsequent trial.

Condition 5 yielded falls and extremely poor performance on all three trials when proprioceptive and visual cues were compromised. This is verified with Condition 6 (platform and visual surround sway-referenced), where poor performance was seen with the first trial and falls were seen with the second and third trials. These findings are consistent with the vestibular dysfunction noted on previous tests and indicate difficulty with functional balance when the child must rely solely on input from the vestibular system. With regard to MCT latencies, results for backward translations are grossly as expected for adults. With forward translations, unusually long latencies (180 msec) were seen for the left via small forward movement and for the right via large forward movement.

VEMP responses could be attained for the right, implanted ear, with both tone-burst and click stimuli. No VEMP tracings were noted for the left, non-implanted ear. Table 3 shows the VEMP parameters obtained for the right ear.

Latencies appear to be consistent with results obtained with hearing children. Amplitudes appear low, but variability has been seen on this measure with adults and with hearing cohorts. This child does exhibit significant vestibular dysfunction that is concomitant with her profound, sensorineural hearing impairment.

Table 2. VEMP tracings for both ears in the second case study.

<table>
<thead>
<tr>
<th>Right Ear</th>
<th>P1 latency</th>
<th>N1 latency</th>
<th>Normalized amplitude</th>
</tr>
</thead>
<tbody>
<tr>
<td>Click</td>
<td>11.1 msec.</td>
<td>16.7 msec.</td>
<td>2.23 microvolts</td>
</tr>
<tr>
<td>500 Hz</td>
<td>14.1 msec.</td>
<td>21.1 msec.</td>
<td>12.1 microvolts</td>
</tr>
<tr>
<td>Left Ear</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Click</td>
<td>11.1 msec.</td>
<td>17.1 msec.</td>
<td>4.97 microvolts</td>
</tr>
<tr>
<td>500 Hz</td>
<td>15.3 msec.</td>
<td>21.3 msec.</td>
<td>7.59 microvolts</td>
</tr>
</tbody>
</table>

Table 3. VEMP parameters obtained for the right ear in case study 3.

<table>
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<tr>
<th>P1 latency</th>
<th>N1 latency</th>
<th>Normalized amplitude</th>
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<tbody>
<tr>
<td>Click</td>
<td>13.3 msec.</td>
<td>20.3 msec.</td>
</tr>
<tr>
<td>500 Hz</td>
<td>14.9 msec.</td>
<td>22.7 msec.</td>
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</table>
lar function may be evaluated successfully with hearing-impaired children through use of the described test battery. RC testing may be adapted for hearing-impaired children and appears to be a viable measure for assessing the VOR. In performing this test, it was important that the clinician incorporate several test frequencies, since some children exhibited normal performance at one test frequency and not another. Tasking was easily performed and instructions provided with integration of auditory and visual cues.

Observance of nystagmic activity served to corroborate RC test findings, and SV measures also provided important contributions. A number of the hearing-impaired children demonstrated hypoactivity with respect to the gain measure, at one or more test frequencies. Future research may explore incorporating additional test frequencies when the patient’s attention span allows, as well as enhanced head stabilization and tasking techniques.

The CDP subtests used were also important contributions to the test battery for evaluating both normal-hearing and hearing-impaired children. SOT subtests 5 and 6 provided especially valuable information when the child relied on vestibular input alone. The clinician may not be able to complete all these trials in view of the subjects' limited attention span.

Future research may also involve enhancing sensitivity of platform sensors for younger children, exploring strategies that children use to maintain balance, further studying all CDP subtests with children, and investigating expected CDP results with various childhood syndromes and disorders.

VEMP measures also may be effectively performed with typically developing and at-risk children, particularly because they are quick, non-invasive, and objective. Replicable tracings are important, and it appeared that the 500-Hz waveforms were more robust than those elicited via click stimuli. As with adult patients, methods to reduce artifact with the amplitude measure should be explored with children, as well as even more effective methodologies for reliable tracings (head and body position, bilateral tracings, etc.).

CONCLUSION
As we think about our first encounter with the pediatric patient, we must consider more optimal screening and case history tools. It is critical to adopt a team approach where audiology works closely with other disciplines that diagnose and treat vestibular disorders.

This article focuses upon three major evaluative tools, but other diagnostic measures are also very valuable, including: thorough audiologic evaluation, bedside/office evaluation, oto-neurologic evaluation, VOG whenever possible, and numerous others.

Vestibular rehabilitation and treatment have become quite state-of-the-art in our adult clinics and further research may also investigate both diagnostic and treatment strategies with children. There are some clinicians who may feel these measures unnecessary with children in view of their highly resilient compensation mechanisms. As with any aspect of our profession, let us consider additional research and clinical work, and make these decisions based on evidence and on viewing
each child individually.

There are available test strategies for testing pediatric patients, based upon adaptation of adult techniques and many children should be tested. The sooner an existing vestibular disorder is identified, the sooner remediation may begin when and if it is warranted.

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REFERENCES