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Artikel Asli/*Original Articles*

The Feasibility of Testing Otoliths and Semicircular Canals Function using VEMPs and vHIT in Malaysian Children

(Kebolehlaksanaan Ujian Fungsi Otolit dan Salur Separuh Bulat Menggunakan VEMPs dan vHIT di Kalangan Kanak-kanak Malaysia)

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ABSTRACT

Early identification of any vestibular dysfunction and balance problem in children is crucial for their general well-being. However the identification process, could be challenging and difficult as compared to adults. We conducted a preliminary study to review our initial experience with ocular and cervical vestibular evoked myogenic potentials (oVEMPs and cVEMPs), video head impulse test (vHIT) and Bruininks Oseretsky Test of Motor Proficiency II (BOT-2) on healthy children and also to determine the feasibility of these tests in this population. Twenty one normal healthy children (12 boys and 9 girls), aged between 6 and 15 years old (mean age, 11.15 ± 2.54 years) participated in the study. They underwent oVEMPs and cVEMPs elicited with bone conduction stimulus via minishaker and air conduction stimulus respectively. All six semicircular canals were assessed using the vHIT. Bilateral coordination, balance, running, speed and agility which are the three subsets of BOT-2 gross motor assessment were conducted for balance assessment. All subjects completed the vestibular and balance assessment except for 1 subject who did not complete the vHIT vertical component. The response rate was 100% for oVEMPs, cVEMPs, and BOT-2, and 95.24% for vHIT. The mean latency and mean amplitude for n10 oVEMPs were 8.88 ± 0.92 and 2.71 ± 1.29, respectively. The mean latency for cVEMPs p13, and n23 were 13.4 ± 1.35 and 21.76 ± 3.71, respectively with interamplitude mean of 97.57 ± 42.69. The vHIT mean for vestibular ocular reflex (VOR) gain were >0.85 for lateral canals and > 0.65 for vertical canals. The mean scale score for bilateral coordination, balance, running, speed, and agility for BOT-2 were 17.52 ± 3.40, 15.14 ± 3.65 and 13.9 ± 5.46, respectively. This study suggest that VEMPs, vHIT, and BOT-2 are feasible test for vestibular and balance assessment in children. Apart from the tests findings, it is hoped that the described experienced and adjustment made in assessing this young population could also be applied by other relevant professionals.

Keywords: Vestibular and balance assessment; children; VEMPs; vHIT; BOT-2

ABSTRAK

Tidak dapat disangkal lagi, identifikasi awal masalah vestibular dan keseimbangan pada kanak-kanak adalah penting bagi kesejahteraan golongan ini. Walau bagaimanapun, proses identifikasi boleh jadi mencabar dan sukar jika dibandingkan dengan golongan dewasa. Kami menjalankan kajian awal ini bagi menilai kebolehlaksanaan ujian-ujian berikut: ocular dan cervical vestibular evoked myogenic potentials (oVEMPs dan cVEMPs), video head impulse test (vHIT) dan Bruininks Oseretsky Test of Motor Proficiency II. Dua puluh satu kanak-kanak sihat berumur di antara 6 hingga 15 tahun (12 lelaki dan 9 perempuan; purata umur 11.15 ± 2.54 tahun) menyertai kajian. Mereka menjalani oVEMPs dan cVEMPs yang dihasilkan masing-masing daripada rangsangan konduksi tulang melalui minishaker dan konduksi udara. Kesemua enam salur separuh bulat dinilai menggunakan vHIT. Bilateral coordination, keseimbangan, larian, pecutan dan kelincahan yang merupakan 3 subset BOT-2 penilaian motor kasar telah dijalankan untuk menilai keseimbangan. Kesemua subjek menjalani penilaian lengkap ujian vestibular dan keseimbangan kecuali seorang tidak menjalani ujian bagi komponen menegak vHIT. Kadar respons adalah 100% bagi oVEMPs, cVEMPs, dan BOT-2, dan 95.24% bagi vHIT. Purata latensi dan amplitud bagi n10 oVEMPs adalah 8.88 ± 0.92 dan 2.71 ± 1.29. Purata latensi cVEMPs p13 dan n23 adalah 13.4 ± 1.35 dan 21.76 ± 3.71, dengan purata interamplitude 97.57 ± 42.69. Purata vHIT untuk gandaan vestibular ocular reflex (VOR) adalah > 0.85 bagi salur sisi dan > 0.65 bagi salur menegak. Purata markah skala koordinasi bilateral, keseimbangan, larian, pecutan dan kelincahan bagi BOT-2 masing-masing adalah 17.52 ± 3.40, 15.14 ± 3.65 dan 13.9 ± 5.46. Dapatan kajian ini menunjukkan kebolehlaksanaan VEMPs, vHIT, dan BOT-2 bagi penilaian vestibular dan keseimbangan pada kanak-kanak. Selain daripada dapatan kajian, adalah diharapkan perkongsian pengalaman kami dalam pengujian golongan kanak-kanak dapat diguna pakai juga oleh profesional yang berkaitan.

Kata kunci: Penilaian vestibular dan keseimbangan; kanak-kanak; VEMPs; vHIT; BOT-2

INTRODUCTION

Disturbance of the normal function in any of the peripheral vestibular end organs may lead to vertigo. Thus, identification of vestibular dysfunction should compromise a comprehensive testing that include testing the semicircular canals (SCCs) and otoliths function for both diagnostic and functional evaluation, as to warrant therapeutic intervention (Rine 2009).

Conventionally, the rotatory chair and caloric test were used for vestibular assessment. However, these tests were poorly tolerated in some children. Rotatory chair has to be done completely in dark environment and this might frighten the children. It also requires space and is costly. On the other hand, caloric test may provoke dizziness, unpleasant feeling, and generally not well received among children.

The advance in technology and research has come up with vestibular testing techniques without inducing dizziness. The otolith dynamic function could be evaluated using ocular vestibular evoked myogenic potentials (oVEMPs) (Curthoys 2010; Rosengren et al. 2005; Todd et al. 2007) and cervical vestibular evoked myogenic potentials (cVEMPs) (Colebatch et al. 1994; Rosengren et al. 2010) while the SCCs could be assessed using video head impulse test (vHIT) (Curthoys et al. 2011).

VEMPs is a myogenic electrical activity in vestibular otoliths receptors that occur in a short duration following stimulation of loud clicks or tone burst via air or bone conduction. These stimulus were shown to preferentially activate otoliths' irregular afferents from the utricular and saccular macula (Curthoys 2010; Curthoys & Vulovic 2011). The activity is recorded from the contraction of sternocleidomastoid (SCM) muscles for cVEMPs and extraocular muscle for oVEMPs. vHIT (Macdougall et al. 2009; Macdougall et al. 2013) is an objective measure of the six SCCs, specifically measuring the vestibular ocular reflex (VOR) gain. vHIT test was useful to detect vestibular pathology, where the dizziness induced test from caloric stimulation can be avoided (Espitia et al. 2014).

A normal function of the peripheral vestibular system results in a good static balance. Since it's introductory in 1978, the BOT-2, a revised version of Bruininks Oseretsky Test of Motor Proficiency (BOTMP) has been used as a standardized clinical tool that incorporated normal reference values used to assess motor proficiency.

Children with vestibular dysfunction have been commonly unnoticed as they were typically not screened or evaluated for vestibular deficits (Weiss & Phillips 2006). Though children may have vertigo, dizziness and/or imbalance, they generally remain silent, especially the younger children (Raglan 2009) due to their inability to describe symptoms accurately. Moreover, to obtain complete clinical history, and to assess vestibular and balance in children were difficult (O'Reilly et al. 2011). Therefore, we conducted a preliminary study to review our initial experience using cVEMPs, oVEMPs, vHIT and BOT-2 for vestibular and balance assessment in children in Malaysia, as well as to determine the feasibility of these tests in children.

MATERIALS AND METHODS

SUBJECTS

Twenty four normal healthy subjects were approached to enroll into the study. Three subjects were excluded as they did not fulfill one of the research inclusion criteria, i.e. to obtain normal tympanogram for middle ear assessment. They were then referred to otorhinolaryngologist for further management. The remaining 21 subjects consisted of 12 boys and 9 girls, aged between 6.1 and 15.1 years old (mean age 11.15 ± 2.54) consented and underwent the vestibular and balance assessment. The subjects were divided into two groups; young age children ($n = 8$; aged between 6 and 11 years old) and adolescents ($n = 13$; aged between 12 and 15 years old). Each subject underwent pure tone audiometry (PTA), tympanometry and distortion product otoacoustic emission (DPOAE) to confirm their hearing status prior to peripheral vestibular and balance assessments. The inclusion criteria for the subjects' participation were normal hearing with 20 dBHL or less at 0.25, 0.5, 1, 2, and 4 kHz, type A tympanometry, and presence of DPOAE responses including no history of balance difficulties upon brief interview with the subjects or parents. The study was approved by the institution ethics committee board (UKMREC Approval Number: UKM 1.5.3.5/244/NN-036-2015; RESEARCH CODE: NN-036-2015) and written consent were obtained from subjects' parents.

VESTIBULAR AND BALANCE ASSESSMENTS

The peripheral vestibular assessments employed in this study were: oVEMPs, cVEMPs, and vHIT. Balance ability of the subjects was assessed with BOT-2, using gross motor subset. One item of close ended question was asked to the subjects during and after each of the test. Estimated length of testing the whole test was recorded and subject's compliance was noted.

OCULAR VESTIBULAR EVOKED MYOGENIC POTENTIALS (oVEMPS)

STIMULUS PARAMETERS

Eclipse EP25 Interacoustic was used to assess both the oVEMPs and cVEMPs. oVEMPs were measured using 750 Hz tone burst, (rise/fall time 0 ms; plateau 2.67 ms) at 50 dBnHL with condensation polarity. The stimulation rate was 5/s. The EMG was amplified and bandpass filtered at the range between 20 Hz to 500 Hz. The duration of each response was 50 ms and averaged at 80 stimuli for each run. The stimulus were elicited using Brüel & Kjær (Naerum, Denmark) minishaker 4810 fitted with a short M4 bolt (2 cm in length) terminated in a bakelite cap (Iwasaki et al. 2008).

RECORDING

The subject was seated on a chair. The active (non-inverting) electrodes were placed on the skin over the inferior oblique muscles beneath each eye, in line with the pupil, for optimum recording. Extra care was employed in identifying and applying the electrodes, as children have smaller surface area and more sensitive skin than adults. Due to the crossed projection of the VOR (Iwasaki et al. 2007), the active electrodes were placed contralateral to the testing ear. This means that the recording from the active electrodes placed at the inferior oblique muscle of the right eye represent the oVEMPs response of the left ear and vice versa. The reference (inverting) electrodes were placed approximately 1-2 cm beneath the active electrodes. The ground electrode was placed on the chin. All recording electrodes were secured in place using surgical tape. The electrodes impedances were kept below 5 kΩ.

A piece of medical tape was placed on the child's forehead (Fz) and marked with an 'X' sign to ensure that the minishaker was placed on the same spot during stimulation, as well as for the child's comfort. During stimulus delivery, the tester stood behind the subject and supported the weight of the hand-held minishaker. The minishaker was held approximately perpendicularly for consistent and repeatable stimuli with little pressure exerted on the subject's Fz (Young 2015) to the bakelite cap. In order to avoid subject's withdrawal and shock, the sound of the minishaker was introduced and the subject was asked to feel the vibration of the minishaker with their hand prior to the actual recording. During recording, the subject must look upward at midline and maintain the gaze (Figure 1) so that the belly of the inferior oblique muscle is brought to the surface electrodes beneath the eyes for optimal recording (Rosengren et al. 2005; Rosengren et al. 2013). The subject's gaze was controlled by instructing him/her to fixate on a particular target, i.e. an attractive but small cartoon sticker on the front wall, placed approximately 20-25 degrees above the child's eye level. A big target should be avoided, as the eyes should not move about while the test was running. The subject was consistently encouraged to maintain the upward gaze position throughout recording.

FIGURE 1. The tester stand behind the subject and hold the minishaker with little pressure on the subject's Fz. The subject look upward to the target placed on the wall

RESPONSES

Suitable oVEMPs was considered to be obtained when there were repeatable and reproducible negative-positive biphasic waveforms elicited. The measurement included the latency (ms) and base to peak amplitude (μV) of the elicited waveforms, labeled as n10.

CERVICAL VESTIBULAR EVOKED MYOGENIC POTENTIALS (cVEMPs)

STIMULUS PARAMETER

cVEMPs was measured with acoustic stimuli of 750 Hz tone burst (rise/fall time 0 ms; plateau, 2.67 ms) at 100 dB nHL using condensation polarity. The stimulation rate was 5/s. The EMG was amplified and bandpass filtered at the range between 20 and 2000 Hz. The duration of each response was 50 ms and averaged at 200 stimuli for each run. The stimulus was delivered monoaurally via ER-3A insert phones.

RECORDING

The active electrode was placed on the skin over the midpoint of the SCM, on each side of the neck. The reference electrode was placed on the clavicle bone and the ground electrode was on the sternum. Ipsilateral recording was employed because the cVEMP is an ipsilateral inhibitory response. The subject was asked to turn his/her head toward the contralateral side of the tested ear (i.e. for right ear stimulation, the subject turned his head to the left and vice versa). In this way the ipsilateral SCM muscle was contracted (Carnaúba et al. 2011; Janky & Givens 2015).

Before instructing the subject to turn his head towards the contralateral side for the SCM muscle activation, the subject was instructed to sit straight. This was to ensure a good cVEMP's responses and ideal activation of the SCM muscle. The subject was not allowed to lean forward or bend backward during recording, to avoid any potential poor responses due to non-optimization of the SCM muscles activation. The subject was instructed to maintain in this position and was encouraged to correct the muscle tension by the visual feedback given through the EMG level meter on the computer screen placed at the side of the subject's head turned. In this study, the preset responses margin for muscle tension were between 35 μV RMS and 150.6 μV (Isaradisaikul et al. 2008). SCM muscle activation was important to ensure an optimum cVEMP's responses (Akin et al. 2004), and larger amplitude is produced by larger contraction of SCM muscle (Colebatch et al. 1994). Five minutes rest period was allowed in between of recordings, to reduce muscle fatigue.

RESPONSES

The measurements for cVEMP were the latency and amplitude of the initial negative-positive biphasic waveform labeled as p13 and n23, as well as the inter-amplitude for p13-n23. The inter-amplitude for p13-n23 was determined based on peak to peak measures of the waveform.

VIDEO HEAD IMPULSE TEST (vHIT)

TEST PREPARATION

vHIT was carried out with ICS Impulse GN Otometric. The subject was instructed to sit upright on a height adjustable office chair. This was to maintain the subject's head at the comfortable height for the tester to deliver the impulse. The subject wore the tightly fitted vHIT goggles. Extra effort was taken in placing the goggle. The strap band was tightened to hold the goggle over the back of the subject's head. The attached sponge on the inner part of the goggle was neatly attached to the bridge of the subject's nose. This was to avoid goggle's slippage when the head is moved during testing as goggle slippage due to improper fitting can negatively impact test results (Curthoys et al. 2014; Hamilton et al. 2015). An addition of small sponge was placed on the bridge of the nose if the goggle did not sit closely (Figure 2). Any head scarf was removed and subjects were instructed not to apply any hair spray to avoid movement of the goggle during head impulse. The subject was given assurance that the discomfort does not last long, and the test only took few minutes to complete.

Before each session of the head impulse, it was important to take enough time to give clear instructions to the subject (Curthoys et al. 2014; Hülse et al. 2015). The subject was instructed to fix their eye and maintain gaze on a target placed on the wall, when the head was moved by the tester. The subject was constantly reminded to fix their gaze back to the target as quickly as possible if they lost the target during the head movement. The target used was an attractive but small sticker, stuck on the wall approximately at the subject's eye level at a distance of 1 meter from the subject. Placing a column of different targets at different heights on the wall is best recommended to avoid bright spots on the pupil (Curthoys et al. 2014).

Subjects were instructed to relax their neck muscle and allow the tester to move their head either laterally or vertically. They were told that they should not assist the head movement as measurement involved was the passive, and unpredictable head movement of the head impulse (Curthoys et al. 2014). Subjects were consistently reminded to minimize blinking and keep their eyes wide open while the test was in progress. They were also requested to avoid excessive eye blinking, because eye blink traces could be difficult to differentiate from corrective saccades, and may even produce false calculated gain if unidentified (Hamilton et al. 2015). The test room was normally lit for optimal pupil dilation. Dark room was avoided as this resulted in pupil enlargement and the eyelids tend to partly cover the pupil, while sunlit room may cause reflections on the goggle's mirror from the infrared component of sunlight and this both conditions will cause poor video image for recording (Curthoys et al. 2014).

RECORDING

During head impulses, the tester stood behind the subject to rotate the subject's head. The subject's eyelid was lifted up to avoid the eyelashes from obscuring the pupil. This was done by lifting up the eyelid manually before placing the goggle on top of the lifted eyelid. Calibration was performed prior to recording. For horizontal testing, the examiners hands were placed on top of the subject's head. For vertical testing, the examiner's preferred hand was placed on top of the subject's head, and the other hand on the subject's chin. Head impulses were delivered randomly with brief, abrupt head turns in the plane of each

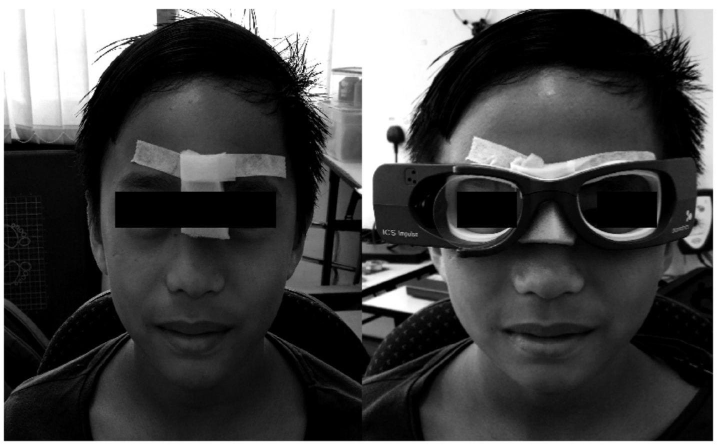

FIGURE 2. A small sponge was placed on the upper part of the nose bridge prior to the goggle placement. This is to fill in the gap between the nose bridge and the goggle to minimize goggle slippage

semicircular canal (horizontal, anterior and posterior). The vertical testing were done accordingly with the matched pairs of the SCC; left anterior right posterior (LARP) and right anterior left posterior (RALP). Performing vertical (anterior and posterior) canals testing were quite tricky as to compare with lateral plane. The subject's eye was ensured to be focusing on a target on the wall with their head and body rotated to either right or left. When testing the vertical plane, the horizontal gaze angle should be aligned with the canal plane under test in order to get correct VOR gain (Mcgarvie et al. 2015). The small VOR gain with no saccade in the traces may be an indicator of wrong eye gaze during the head impulses.

During head impulse, the band or the cable of the goggle should not be touched as this may cause goggle slippage resulting inaccurate vHIT's responses. The head rotation was maintained at an angle of 10 to 20 degree velocity at 100 degree/s – 250 degree/s and acceleration of 1000 degree/s^2 – 2500 degree/s^2 Subjects were given approximately 3 minutes rest in between different head impulse axis. Subjects were constantly reminded to maintain looking at the target while the test was running. Twenty averages were obtained for each SCC.

RESPONSES

Responses were recorded in terms of VOR gain for each SCC and this was automatically calculated by the software. The VOR gain is defined as the ratio of eye velocity to head velocity. Appearance of any saccades was also observed.

BRUININKS-OSERETSKY TEST OF MOTOR PROFICIENCY SECOND EDITION (BOT-2)

TEST PREPARATION

Subject's gross motor performance was assessed using the BOT-2 Gross Motor subset: bilateral coordination (Subset 4), balance (Subset 5), and running, speed and agility (Subset 6). The BOT-2 bilateral coordination subtest has 7 items, balance subset has 9 items, and running, speed and agility subse t has 5 items (Table 1). The area for the running course was cleared from any obstacles. The subject was reminded to wear suitable attire for sport activity, including sport shoes prior to the testing.

TESTING

Subject's leg preferences (as described in the BOT 2 manual) were determined prior to implementing the exercise. The tester then demonstrated the exercise to the subject. The image of a child doing the task or exercise provided in the BOT-2 Gross Motor Administration Easel was also used to aid the verbal instruction to the subject. The subject was instructed to perform all the items in each subtest and given at least two trials in case they fail to perform successfully in the first trial.

SCORING

The score of each item performed was calculated separately. In item that was performed twice, the highest score attained between the trials will be acknowledged as the score for the item. The raw score was then converted into point score, and the summed point score produced the total point score. The total point score was then converted to scale score and the subject's age at the time of the test performed was then compared to the age-matched normative score provided in the manual.

CLOSE ENDED QUESTION

One close ended question was administered during and after the test's session. The question asked was "Do you feel any pain?"

STATISTICAL ANALYSIS

All statistical analyses were performed using IBM SPSS (Statistical Program for Social Sciences) version 22. Paired *t*-tests and Wilcoxon signed rank test were used to compare the latencies and amplitudes of VEMPs and vHIT between ears. Independent *t*-test and Mann-Whitney test

TABLE 1. Bruininks Oseretsky Test of Motor Proficiency Gross Motor Subtest

Bilateral coordination item	Balance item	Running, speed, and agility item
Touching nose with index finger – eyes closed	Standing with feet apart on a line – eyes open and closed	Shuttle run
Jumping jacks	Walking forward on a line	Stepping sideways over a balance beam
Jumping in Place – same and opposite side synchronized	Standing on one leg on a line – eyes open and closed	One legged stationary hope
Pivoting thumbs and index finger	Walking forward heel to toe on a line	Two legged side hop
Tapping feet and finger – same and opposite sides synchronized	Standing on one leg on a balance beam – eyes open and closed Standing heel to toe on a balance beam	

were used for comparisons between age and gender group. One sample *t*-test was used to compare the BOT-2 score with the published normative data. Pearson correlation was used to determine the relationship between age and cVEMPs parameters and BOT-2 score. Significance value was set at $p < 0.05$.

RESULTS

All 21 subjects completed the oVEMPs, cVEMPs, vHIT, and BOT-2 except for 1 subject who did not complete the vHIT vertical testing. The response rate was 100% for oVEMPs, cVEMPs and BOT-2, and 95.24% for vHIT. None of the subject complained of pain during and after the test in the close ended one item questionnaire. The total test duration for each subject varied, depending on their age and cooperativeness. Estimated duration for the whole vestibular and balance assessment (including subjects' preparation) was at an average of 80 minutes (ranges from 45 to 100 minutes). All the tests including the pre-assessment tests were completed on the same day, except for 4 subjects that were called to come again to complete the whole test due to time constraint.

oVEMPs AND cVEMPs

There were no statistically significant ear effects for the oVEMPs n10 latency (t = -.244, p = .809) and n10 amplitude (t = .191, p = .850) as well as the cVEMPs p13 latency (t = .231, p = .820), and cVEMP p13 – n23 interamplitude (t = 1.030, p = .315). Wilcoxon signed rank test for n23 latencies also showed no significant ear effects. Accordingly, the results for oVEMPs and cVEMPs were collapsed, resulting in descriptive statistics being calculated for a maximum of 42 individual ears. Table 2 shows the average latencies and amplitudes for oVEMPs and cVEMPs values as well as their range for the total cohort. There was statistically significant differences for oVEMPs n10 latency between gender ($t(40) = -2.316$; $p < 0.05$). cVEMPs n23 latency showed statistically significant differences between two aged groups. Consistently, age was found to be correlated with cVEMPs n23 latency (r = .47; p = 0.01), indicating cVEMPs n23 latency prolong with age (Figure 3). Figure 4 showed an example of (a) oVEMPs and (b) cVEMPs' traces in a subject for both ears.

VHIT

One subject did not complete the vertical plane impulse (for both LARP and RALP, n = 20). The mean for the VOR gain for the right lateral SCC was 0.98 ± 0.07, and 0.94 ± 0.07 for the left lateral. The mean for the VOR gain for the right anterior was 0.79 ± 0.14, and left posterior was 0.73 ± 0.11. The mean VOR gain for left anterior was 0.84 ± 0.11 and the right posterior was 0.92 ± 0.12 (Table 3). The mean for the lateral VOR gain showed statistically significant ear effect (t = 3.732, p = 0.001). There was no significant difference between the mean VOR gain and age as well as gender. Figure 5 showed an example of complete vHIT response in a tested subject.

BOT-2

In this study, the subjects were instructed to perform all items in the gross motor subset of BOT-2; the bilateral coordination, balance, and the running, speed and agility. Strength subset was excluded as it was too laborious for

TABLE 2. oVEMPs and cVEMPs latencies and amplitudes (mean ± SD)

VEMPs parameter	Total ears (n = 42)	Range
oVEMPs		
n10 latency/ms	8.88 ± 0.92	7.33 – 11.67
n10 amplitude/µV	2.71 ± 1.29	1.03 – 6.04
cVEMPS		
p13 latency/ms	13.44 ± 1.35	11.33 – 17.83
n23 latency/ms	21.25 ± 2.10	18.33 – 28.83
p13-n23 interamplitude/µV	97.57 ± 42.69	32.84 – 241.65

TABLE 3. Vestibular Ocular Reflex (VOR) gain in tested subjects

	Right Lateral	Left Lateral	Right Anterior	Right Posterior	Left Anterior	Left Posterior
n	21	21	20	20	20	20
Mean	0.98 ± 0.07	0.94 ± 0.07	0.79 ± 0.14	0.92 ± 0.12	0.84 ± 0.11	0.73 ± 0.11

n = number of subjects

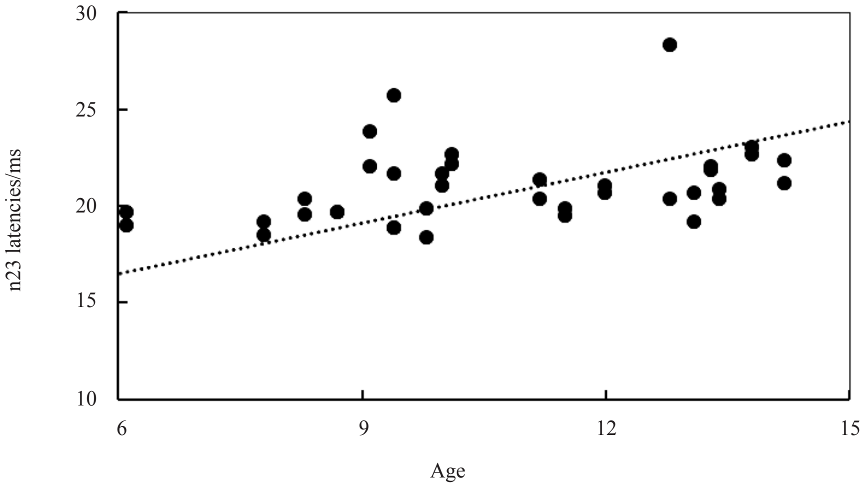

FIGURE 3. n23 latencies prolonged with age

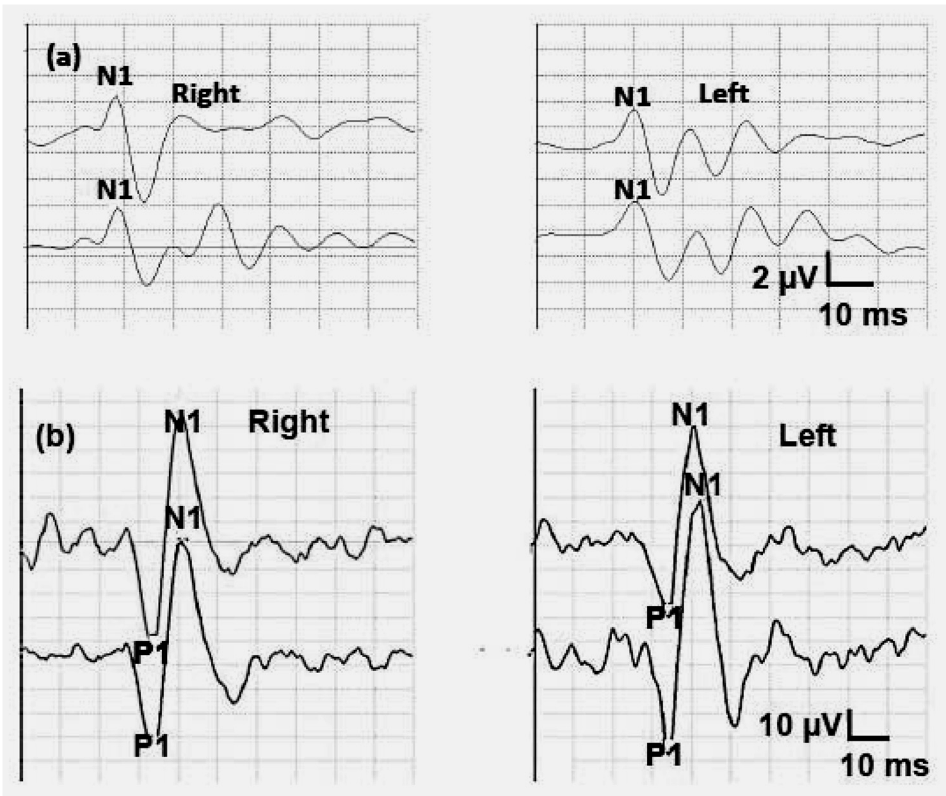

FIGURE 4. Top (a) oVEMPs traces with n10 labelled as N1 at around 10 ms for right and left, and bottom (b) cVEMPs traces for right and left, with p13 labelled as P1 at around 13 ms and n23 labelled as N1 at around 23 ms

the subjects, as well as to avoid subject's fatigue because the items in the strength subset required a lot of effort from the child to perform them. The mean scale score for bilateral coordination was 17.52 ± 3.40, balance mean scale score was 15.14 ± 3.65 and mean scale score for running, speed and agility was 13.90 ± 5.46. There was a significant difference between the scale score obtained for bilateral coordination and the published normative data (t(20) = 3.401). The descriptive category according to the mean scale score was "average" for each subset. There were no significant differences between the scale scores and gender or age groups, however there were negative correlation between age and the scale scores for running, speed, and agility (r = .454, *p* = 0.02) (Figure 6).

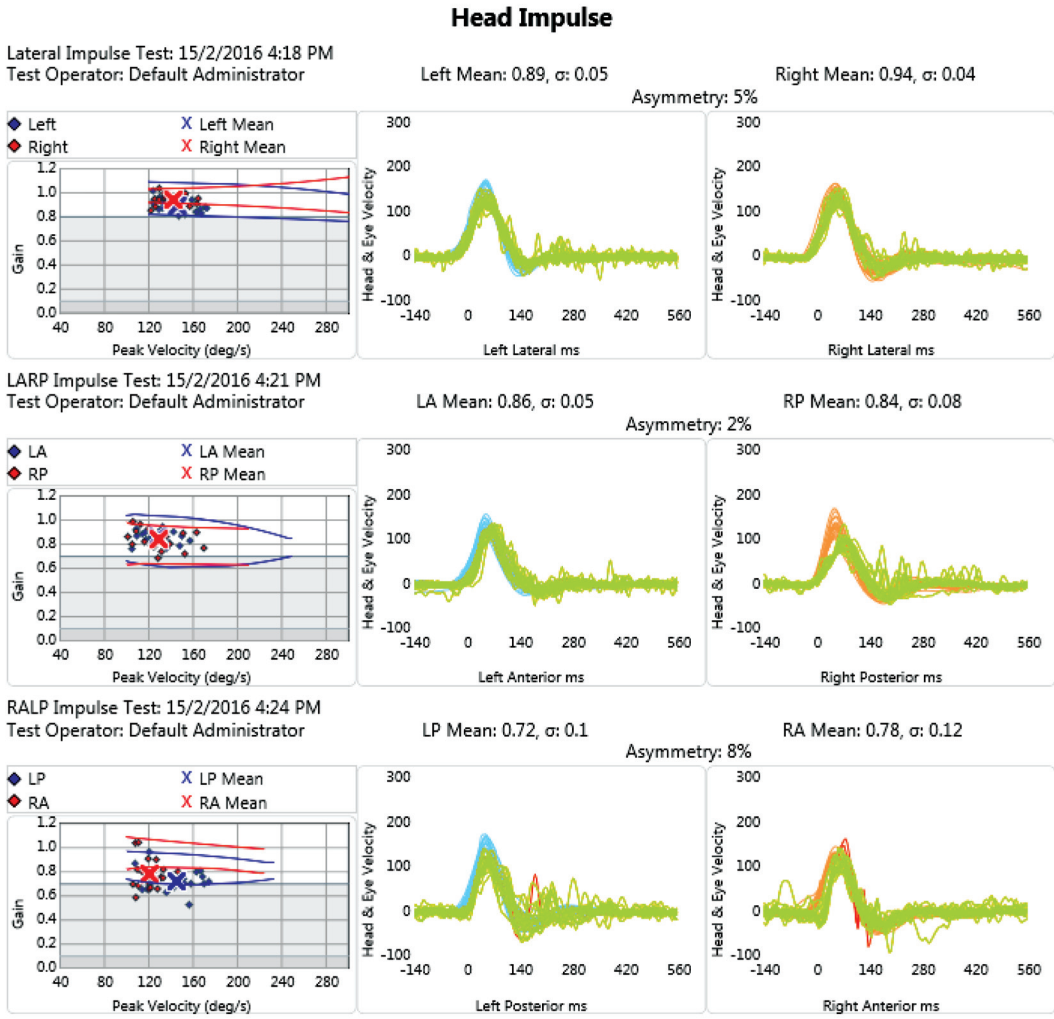

FIGURE 5. Video head impulse test (vHIT) results for all SCC planes. The boxes on the left showed the VOR relative to peak head velocity with the diamonds representing each individual head impulse and the X's representing the mean gain for each canal (red = right; blue = left). Waveforms on the right represent head (red = right; blue = left) versus eye (green) movement. The top row showed right and left lateral canal tracings, middle row for left anterior and right posterior tracings and bottom row for right anterior and left posterior. The mean gain value for each canal is seen. (Images adapted from ICS Impulse software, GN Otometrics, Denmark).

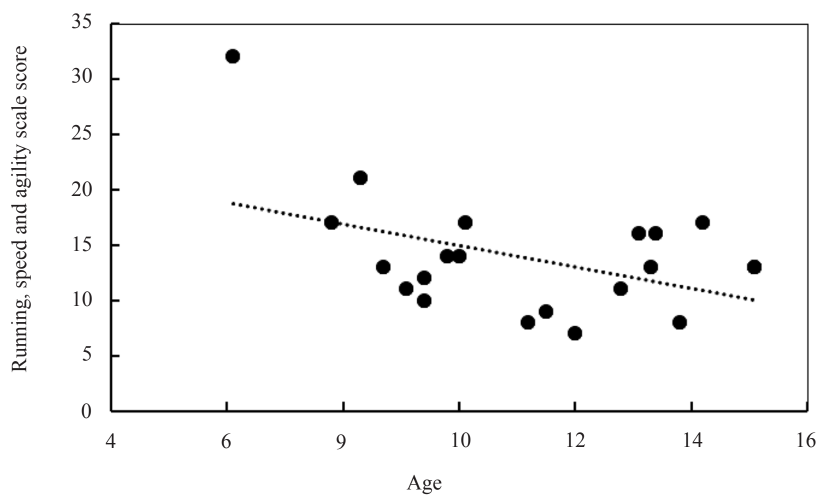

FIGURE 6. Scale score for running, speed and agility reduced with age

DISCUSSION

Children seldom report or hardly express any discomfort feeling to adult if problems of vestibular and balance appeared. Even adults, the parents or the caretaker may not fully understand on existence of any problems on vestibular and balance thus resulting in ignorance in managing them. Relating to that, vestibular and balance assessment in children is urgently required before approaching any treatment to provide better management, that is essential for their general well-being.

This preliminary findings with the small sample of subjects (n = 21) suggest that vestibular and balance assessment using oVEMPs, cVEMPs, vHIT and BOT-2 are feasible in children, as young as 6 years old, in our population. All subjects with an exception of 1 subject, complied with the whole test procedures and none of them complaint of pain during and after administration of each test.

oVEMPs

The response rate of oVEMPs was 100% in our study. This finding supported the previous report by Chihara et al. (2007) that concluded the oVEMP response was present in the majority of young neurologically and otologically healthy subjects. Piker et al. (2011) also reported a 100% response rate of oVEMP in the younger age cohort group. In another study, the oVEMP response rate were also reported as 100% for the subjects group aged 4 to 13 years old (Wang et al. 2013). The mean n10 latency value in this study was 8.88 ± 0.92 ms. This latency value was much shorter (1-4 ms) than those reported in previous studies (Chihara et al. 2007; Piker et al. 2011; Todd et al. 2007; Xu et al. 2015). Similarly, Iwasaki et al. (2008) also reported of slightly longer latencies in oVEMPs elicited using minishaker in adult subjects.Young (2015) reported on the norm n10 latency as 11.1 ± 0.9 ms for children aged 3 years old onwards and adult. However, our study finding of mean latency was consistent with report by Chou et al. (2012) where their n10 mean latency was 8.0 ± 0.7 ms. Our study findings also showed a statistically significant difference in oVEMPs n10 latency between gender. Another study on gender effect to the oVEMPs parameter by Sung et al. (2011) also showed gender difference however in n10 amplitude. They reported that the difference may be attributed to variance in the muscle bulk between male and female.

The measurements for our n10 amplitude were from the baseline to the initial peak of n10. Our mean amplitude was very small compared to the mean amplitude reported by Iwasaki et al. (2008) in healthy adults. While Chou et al. (2012) reported n10 amplitude as the measurement of n1-p1 peak and showed no difference in the mean amplitude between children and adult. The reason for the small n10 mean amplitude in our study could be because of gazing upward and maintaining the gaze upward were quite intolerant in children. For optimum oVEMPs recording, gazing upward was essential (Iwasaki et al. 2008). However, most children tend to lift up their head when instructed to look upward, which could then resulted in amplitude decline or even no response generated (Hsu et al. 2009).

cVEMPs

We successfully recorded cVEMPs bilaterally in all subjects. The recorded mean latencies for p13 (i.e.13.4 ± 1.35 ms) was consistent with the report in the early work done by Colebatch et al. (1994) and also consistent with recent studies (Erbek et al. 2007; Jafari & Malayeri 2011; Janky & Shepard 2009; Wang & Young 2006). In a study involving children aged 3 to 15 years old, Picciotti et al. (2007) reported similar results to adults and showed no difference in the cVEMPs parameters' values with age groups. Our n23 mean latencies (i.e. 21.25 ± 2.0 ms) finding was comparative with previous studies report (Erbek et al. 2007; Isaradisaikul et al. 2008; Wang & Young 2003). Consistent with our findings, Janky and Givens (2015) also reported cVEMPs n23 latency increases with age. They suggested that this measure could be explained similarly with the relation of p13 latency with neck length differences (Chang et al. 2007) and it may be the trend when examining children.

The norms of VEMPs differ between clinics. Moreover, the variety of protocols to evoke VEMPs including stimulation type and intensity, number of stimuli, testing position for muscle activation, electrode montage and EMG level would definitely resulted in different values (Isaradisaikul et al. 2012). Different plateau time used were also found to affect the p13 latency (Marimuthu & Harun 2016). The value from our findings however is still within the range in the standardized norm from the past study.

vHIT

We performed all SCC's planes for vHIT testing on all subjects, with an exception of 1 subject. There were significant differences in the lateral mean VOR gain and this could be explained by the handedness of the tester. Nevertheless, the results obtained were within the expected normal values. Typical results in a healthy person for VOR gain in vHIT is about 1.0 where the VOR gain is defined as the ratio of eye velocity to head velocity (Curthoys et al. 2014).The mean VOR gain for lateral plane was consistent with a study findings in young adult group by Patterson et al. (2015). In a preliminary study on vestibular, visual acuity and balance outcomes in children with cochlear implants reported that the VOR gain was normal with the value of >0.85 for lateral canals and >0.65 for vertical canals (Janky & Given 2015).

We implemented head hand placement technique for the lateral head impulse in this study. Although another hand placement technique (chin hand placement) revealed averaged normal VOR gain (Macdougall et al. 2009), study on effects of hand placement by Patterson et al. (2015) showed a higher gain values in head hand placement technique for both younger and older adults. They also suggested that clinicians performing the impulses should select one method for protocol consistency.

BOT-2

All subjects showed good performance in all 3 subsets of BOT-2 gross motor function. Our subjects' mean scale score for bilateral coordination (17.52 ± 3.4) was slightly higher than the published age-adjusted mean 15 ± 5 while the mean scale score for running, speed and agility subset were lower (13.90 ± 5.46). The mean scale score for balance (15.14 ± 3.65) was about the same value with the published age-adjusted mean. Our finding for balance subset scale score was comparative with the study outcome done by Cushing et al. (2008) on control group on static and balance function in children. The difference in findings in our study compared to the published age-adjusted mean could be due to the contribution of different culture and environment of the subject's life style, which may affect the skill and ability of the motor activities (Chow et al. 2001; Hickey et al. 2000 and Schneider et al. 1995). This current study showed scale score for subset running, speed, and agility were negatively correlated with age. This finding could indicate that as child grows their physical fitness might drop. However these findings must be interpreted with caution as the sample was small. A larger number of subjects study are important to be able to derive a Malaysian normative scale score for BOT-2.

To date, there was no report on vestibular and balance assessment in normal children in Malaysia, thus this study finding could potentially be used as reference for expected values on oVEMPs, cVEMPs, vHIT, and BOT-2. Testing on children was indeed a challenging task for the tester, especially children with very young age. The Instructions must be clearly given and frequent reminder must be given for any task. To get their cooperation last longer, acknowledge them in each of the successful task and also give encouragement for them to improve if they performed inappropriately. Give them assurance that all the procedures involved will not cause any harm or pain.

We would also like to suggest preferred strategies for each vestibular and balance assessment when testing on children, for a better recording. For oVEMPs testing with minishaker, always let the child feel the vibration prior to placing it on Fz. Even though clear instruction has been given prior to the testing, always check whether they are performing the task correctly. For example, during oVEMPs recording, one of the children was actually not looking upward at the target fixed centrally on the wall above their eyes even though instructed, but instead she looked at other point on the wall. This resulted in poor response and the need to repeat the test.

In our experience, to elicit a good cVEMPs, the activation of SCM muscle was best achieved when the body was straight without bending or leaning against the chair, the moment the child turned the head to the contralateral side of the tested ear. They were also instructed to monitor the visual feedback provided and maintained the best position within the preset margin level.

Tightening the vHIT goggle was a bit difficult in some children with small head circumferences and/or low nose bridge. At the moment, there is no special goggle available for pediatrics. We had made modification by placing an additional sponge secured by surgical tape at the child's upper nose bridge (Figure 2). This is important to minimize goggle slippage during the head impulse. Children like to move the goggle once it was placed on their head, moreover they felt slightly discomfort due to the tightness. The child need to be reminded not to move the goggle especially after goggle calibration and to wait patiently until the test end before they are allowed to remove the goggle.

For BOT-2 testing, the items to complete were quite interesting and majority of the children enjoyed accomplishing the task. However, the tester needs to advise them not to laugh and give full concentration while performing the task or else the performance will be affected. Encouragements were given frequently during the session to further motivate them. Give them breaks in between items or subset to gain their energy before completing the whole session.

CONCLUSION

We found that vestibular and balance systems assessment using oVEMPs, cVEMPs, vHIT and BOT-2 are feasible and reliable in normal healthy children. We would also like to recommend that these assessment to be included as part of clinical routine protocol in some tertiary vestibular and balance assessment clinic. Apart from the tests findings, it is hoped that the described experienced and adjustment made in assessing this young population could also be applied by other relevant professionals.

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