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Original Research Article

Test-retest reliability of the computerized rotational head impulse test in the pediatric population

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ABSTRACT

Background: This study aimed to determine the test-retest reliability of the computerized rotational head impulse test (crHIT) as an additional clinical tool to assess horizontal semi-circular canal (HSCC) function in pediatric population.
Methods: To determine the test re-test reliability of the crHIT, the study included 29 normally developing children with a mean age of 12.2 years±2.7 (range: 8-17 years) with no history of vestibular symptoms and disorders. Participants underwent two crHITs within one session and one crHIT in the following session. Each crHIT included one protocol using an earth fixed target. The test-retest reliability was determined using a quantitative research approach with a repeated measures design.
Results: Mean angular vestibulo-ocular reflex (aVOR) gain of 1.01 (session 1), 1.00 (session 2), and 1.01 (session 3) were obtained. Regression analysis revealed no significant difference for leftward rotations within-session (p=0.608) and between-session (p=0.318) for the differences measured. The same was seen for rightward rotations revealing no significant difference within-session (p=0.631) and between-session (p=0.523).
Conclusions: The crHIT is a reliable clinical tool in assessing HSCC functioning in the pediatric population as it demonstrates good test-retest repeatability. The crHIT is a valuable complementary assessment to the video head impulse test (vHIT), since it is well tolerated by children, it is simple to administer and head velocities of >100°/sec are easily attainable. Extending the pediatric vestibular test battery with crHIT can be a valuable diagnostic tool without adding to the overall test time.

Keywords: Clinical tool, Computerized head impulse test, Horizontal semi-circular canal functioning, Pediatric vestibular assessment, Vestibular test battery

INTRODUCTION

Childhood vestibular disorders negatively affect intellectual and physical development, as they can cause learning difficulties, delays in gross motor skills and spatial problems.[1,2] While vertigo is not as common in children as it is in adults, it is more likely to go unnoticed in children due to their failure to express the symptoms they are experiencing.[1-3] A systematic review done by Gioacchini and colleagues reported a prevalence of up to 15% of vestibular disorders in the pediatric population, with the most common disorders being benign paroxysmal vertigo of childhood and vestibular migraine.[1-4] In the past, physicians were quick to refer a child with vertigo for cross-sectional imaging such as computerized tomography or magnetic resonance imagining, however this is not always justified due to the risks of side effects of premedication and general

anaesthesia often required for these scans and financial impact of such expensive scans.[5] Such a child must first undergo full oto-neuro-vestibular clinical examination, an ophthalmologic examination, and an audiovestibular examination, unless neurological symptoms are present.[5]

Better differential diagnoses are essential in guiding and improving intervention for these children, as intervention is dependent on diagnosis made by health care professionals.[6] Gedik-Soyuyuce et al emphasized the possibility of obtaining a more accurate diagnosis when using multidisciplinary team and functional vestibular testing which has been adapted to be age-appropriate.[6] Rodriguez and Janky further looked at using quantitative semi-circular canal tests including video head impulse testing, rotary chair testing, and caloric testing for certain ages and explained which modifications can be made to make tests more child friendly.[7]

Caloric testing has long been the highest standard for assessing the HSCC functioning in adults and children.[7] This test, however, is not well tolerated by children because the air or water irrigation can cause dizziness.[7] A further drawback to caloric testing is that it only assesses canal functioning at low frequencies using a non-physiological stimulus.[7] Rotary chair testing is also being used for children. This test is very child friendly as the child can sit on an adult's lap during rotations and the eyes can be monitored using goggles or tracking cameras. However, during rotary chair testing canals are stimulated together instead of separately. Rotational testing is therefore effective in identifying bilateral vestibular losses, but it don't provide a practitioner with information about the individual canals.[7] Over the last few years, the video head impulse test (vHIT) has become a great tool in assessing individual HSCC at higher frequencies.[8] This test is very well tolerated by children and can also be done using a remote camera system instead of goggles.[9] When specifically looking at the pediatric population, Ross and Helminski observed challenges in the vHIT system.[8] Due to children's smaller physical features, such as smaller head size and smaller eyelid openings, measurement errors seem to occur more easily than in adults.[8] Another downside is that results are dependent on the experience and skills of the examiner to elicit correct and precise impulses. Additionally, a lack of inherent stiffness of the cervical spine is observed in the pediatric population, resulting in difficulty eliciting a head impulse greater than 100°/sec^2.8 Head impulses delivered at greater than 100°/sec^2 saturation stimulate a response of the vestibular nuclei, which takes place on the ipsilateral side of the lesion to reveal a present asymmetry.8 In some patients the aVOR gain may seem normal when using slower impulses, however, when the peak head impulse velocity is increased, the loss becomes clear.[10]

Furman and colleagues intended to help overcome some of these challenges observed in caloric testing, rotary chair, and vHIT by using the recently developed computerised rotational head impulse test (crHIT).[11] To administer crHIT, the system uses a rotary chair and a head mounted video-oculography (VOG) system that includes head tracking sensors and a target generating system. The same physiological principles are used with the crHIT as those that apply to the vHIT. These physiological principles imply that a natural stimulus, head rotation, is used to evoke the aVOR generating a corrective eye movement.[12] By using the chair to induce these impulses, the crHIT uses whole body rotations whilst the VOG records the eye movements.[11] These automated impulses are referred to as computerized because they are not dependent on an examiner.

Furman and colleagues found that the crHIT doesn't require a very well-trained test administrator, unlike the vHIT.1[1] The crHIT also requires a smaller number of impulses, since each impulse is accurately and specifically defined and provides more patient comfort when compared to the vHIT. Furthermore, the crHIT prohibits prediction from the patient, because of pseudo-random direction and magnitude of turn.[11] The crHIT is additionally not affected by inherent stiffness of the neck, as it utilizes whole body rotations and could therefore possibly overcome this challenge noted for the vHIT in children. Moreover, the crHIT is able to elicit impulses greater than 150°/sec^2, which are needed to identify the asymmetry in compensatory eye movements.[8,11]

When considering the above-mentioned benefits of the crHIT, it becomes clear that the crHIT shows great potential in supplementing the pediatric vestibular test battery to quantify the vestibular loss of each HSCC individually when vHIT cannot be done reliably. This could further be aiding healthcare practitioners in making a more accurate diagnosis. As seen in the study done by Ross and Helminski we also hypothesize that the aVOR gain will not be influenced by age.[8] The crHIT is not a recognized testing procedure for children yet, therefore the aim of this study was to establish the clinical validity of the crHIT in the pediatric population, by determining the test-retest reliability of the crHIT in a typically developing pediatric sample and describing how they respond to the procedure.

METHODS

The study was conducted at the department of speech-language pathology and audiology at the university of Pretoria in South Africa in 2021. Ethical approval was obtained from the university of Pretoria research and ethics committee of the faculty of humanities (approval number: HUM022/1220) prior to data collection. Before any data collection was performed, written consent was obtained from participants' legal guardians and written informed assent obtained from participants respectively.

Participants

The study population consisted of 29 typically developing children and adolescents between the age of 8

and 17 years. All participants were recruited using convenience sampling. The following was done to determine if participants met the inclusion criteria:

Participant information form

A self-developed participant information form was completed by the legal guardian of the participant. This form determined whether the participant has had previous surgery and/or trauma to the head, neck or ear, a diagnosed hearing loss or presented with vestibular symptoms such as imbalance, dizziness, or vertigo. If one of these were present, the participant was excluded from the study.

Developmental assessment schema (DAS)

Participants were included in the study if they presented with typical development from birth. Typical development was determined using the DAS, only looking at the category gross motor skills being met in a timely manner.[13]

vHIT screening

The ICS impulse system, with OTOsuite vestibular software (GN Otometrics, Taastrup, Denmark) was used for lateral vHIT testing to screen for HSCC functioning. Participants were included if they presented with normal lateral semi-circular canal (SCC) vHIT results. Lateral vHIT results were considered normal if the gain obtained was between 0.8 - 1.2 without the presence of covert or overt saccades.[14]

Procedure

The crHIT was delivered via the neurolign neuro-otologic test centre (NOTC) within a light proof booth (model no. RCS-035). An FDA-cleared motion and eye-tracking device manufactured by neurolign USA, LLC (formerly known as neuro kinetics, Inc.; Pittsburgh, PA) was used to record eye movements. The whole-body rotations administered by the rotary chair were controlled by the software version 8.0.2 of the VEST™ installed on the NOTC. Each participant underwent three crHIT assessments. The crHIT 1 and 2 were conducted within the same session. The crHIT 3 was conducted within approximately 4 weeks of the first session. The exact time interval between tests were randomized according to the time disposal of each participant's weekly schedule. For the crHIT, participants were seated and firmly strapped to the rotary chair in the light proof booth. Head restraints were used to secure the head from moving during rotations and VOG goggles were securely fastened to the participant's head. In the case of smaller participants, a car booster seat was secured to the chair using tie down straps to elevate the child that the head restraints could be properly applied. During each crHIT 12 uninterrupted whole-body rotations were delivered by the rotary chair through abrupt random accelerations in a clock-wise (CW) or counter clock-wise (CCW) direction. The administered accelerations ranged pseudo-randomly from 999°/sec^2 to 1066°/sec^2, with peak head velocities of 150°/sec and 160°/sec. During these accelerations, the participants were instructed to keep their gaze on a stationary target 1m away for as long as they could.

Data analysis

Data analysis was conducted using Microsoft excel and the statistical software program IBM SPSS (version 25) to perform descriptive and inferential statistics. For each participant the crHITs 1 and 2 were utilized to assess within-session reliability and the crHITs 2 and 3 were compared to assess between-session reliability. Shapiro-Wilk test of normality revealed a normal distribution of the data, therefore parametric statistical tests were used. For this study the one-way repeated measure analysis of variance (ANOVA) used to test for linear relationship between differences and averages. Next, the limits of agreement (LoA) method and repeatability coefficient (RC) were utilized for assessing consistency in measurements within-sessions and between-sessions.[15-17] For the LoA method the mean difference was calculated using the t test to determine possible present bias. Thereafter the LoAs were calculated for the average of the differences. Additionally, the upper and lower limit confidence intervals (CI) were determined. To confirm the LoA tested the RC was also calculated using all three sessions. Finally, the error rate between the three sessions was calculated to indicate average differences between the three measurements for the same participant.

RESULTS

Participants had a mean age of 12.2±2.7 years (age range: 8-17 years). The sample consisted of equal sex distribution (52% female). To ensure equal age distribution of younger children and adolescents, participants were divided into two age groups, children and adolescents, respectively: 8-12 years (n=13, 46%) and 13-17 years (n=15, 54%). For two participants data was only used for test session 1 and 2. The one participant was unable to attend the third session and the other had excessive blinking during session 3 and therefore the data had to be omitted from analysis.

The following mean aVOR gain results were obtained for each participant during each testing session for right and left rotations combined (Figure 1). The standard deviations (SD) measured were 0.030 (session 1), 0.031 (session 2) and 0.036 (session 3).

The results shown are presented for crHIT gain outputs. Since each participant was measured three times, the statistics are presented using the Bland-Altman plot separately for measurement 1 vs. 2 (within-session) and for measurement 2 vs. 3 (between-session). In addition, using a repeatability coefficient (RC) and the

corresponding statistics, we refer to all three measurements together.[17]

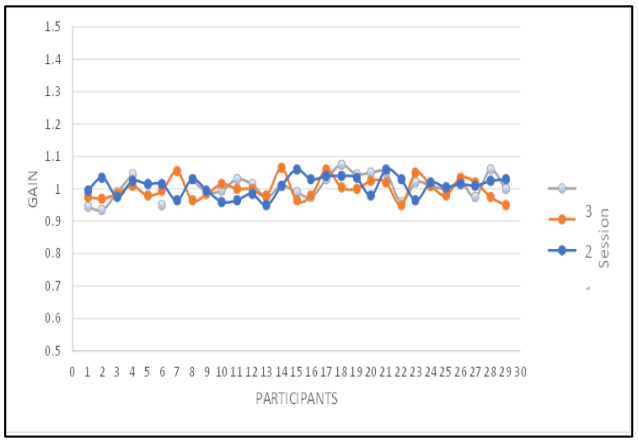

Figure 1: Mean gain. Points represent mean gains of each participant for session 1, 2 and 3.

Regression analysis

The one-way repeated measure ANOVA revealed that for the crHIT leftward rotations the regression of the differences on the average (slope) was not statistically significant, when comparing the first two sessions (p=0.608) and the last two sessions (p=0.318), indicating that there is no linear relationship between the differences and the averages. The same was found for the rightward rotations. The regression of the differences on the average (slope) was also not statistically significant for the rightward rotations, when comparing the first two sessions (p=0.631) and between the last two sessions (p=0.523), indicating that there is no linear relationship between the differences and the averages. The bias computation was taken directly from the differences.

LoA method

Bias analysis

For this study, bias is the mean difference between the sessions. The bias analysis using the t test indicated that the mean differences were not statistically significant for leftward rotations when comparing within-session (p=0.246) and between-session (p=0.138), revealing no evidence of bias. For rightward rotations the bias analysis also indicated that the mean differences were not statistically significant as for leftward rotations when comparing within-session (p=0.582) and between-session (p=0.837), also revealing no evidence of bias.

Limits of agreement

The standard deviation of the differences was used in the computation of the limits of agreement. For leftward rotations the 95% LoA interval for within-session was -0.120 (lower limit) and 0.095 (upper limit) and for between-session -0.071 (lower limit) and 0.096 (upper limit). For rightward rotations the 95% LoA interval for within-session was -0.117 (lower limit) and 0.105 (upper limit) and for between-session -0.107 (lower limit) and 0.111 (upper limit). The LoA are graphically depicted in the Bland-Altman plot for within-session (1 vs 2) and between-sessions (2 vs 3) (Figure 2 and 3, respectively). Additionally, the lower and upper CI of the LoA were calculated and are presented in Table 1.

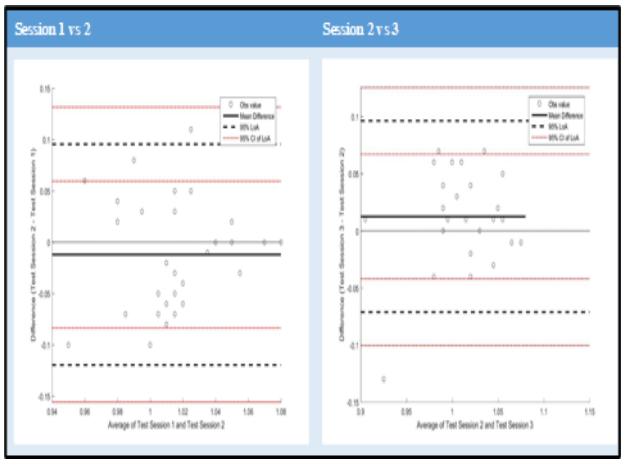

Figure 2: Bland-Altman plot (leftward rotations).

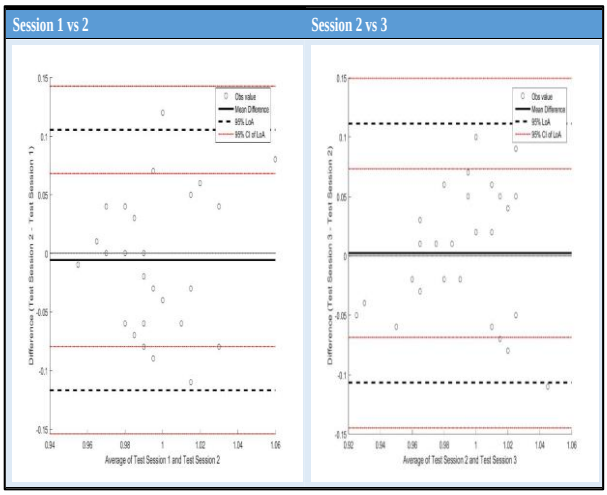

Figure 3: Bland-Altman plot (rightward rotations).

Table 1: CI for lower and upper LoA.

Sessions	Leftward rotations				Rightward rotations			
	95% CI for lower LoA		95% CI for upper LoA		95% CI for lower LoA		95% CI for upper LoA	
	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper
1 vs 2	-0.156	-0.084	0.059	0.132	-0.154	-0.080	0.068	0.143
2 vs 3	-0.100	-0.042	0.067	0.126	-0.145	-0.069	0.073	0.149

Table 2: The within-subject variance and repeatability coefficient (leftward rotations).

Number of sessions (K)	Sq. root of within-subject variance			Repeatability coefficient			Error rate
	$\hat{\sigma}_w$	95% CI for σ_w		RC	95% CI for RC		$CV_w = \sigma_w/\mu$
		$\hat{\sigma}_{w,L}$	$\hat{\sigma}_{w,U}$		RC_L	RC_U	
3	0.038	0.032	0.046	±0.104	0.088	0.127	3.7%

Table 3: The within-subject variance and repeatability coefficient (rightward rotations).

Number of sessions (K)	Sq. root of within-subject variance			Repeatability coefficient			Error rate
	$\hat{\sigma}_w$	95% CI for σ_w		RC	95% CI for RC		$CV_w = \sigma_w/\mu$
		$\hat{\sigma}_{w,L}$	$\hat{\sigma}_{w,U}$		RC_L	RC_U	
3	0.037	0.031	0.045	±0.103	0.087	0.125	3.7%

Table 4: Comparing 95% CI for LoA with 95% CI for RC.

Sessions	Leftward rotations				Rightward rotations			
	95% CI for limits interval (LoA)		95% CI for RC*		95% CI for limits interval (LoA)		95% CI for RC*	
	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper
1 vs 2	-0.120	0.095	0.088	0.127	-0.117	0.105	0.087	0.125
2 vs 3	-0.071	0.096			-0.107	0.111		

*lower and upper limits for all three sessions combined.

RC method

The RC was calculated using all three measurements as presented in Table 2. For leftward rotations the following RC was calculated. Note that the difference between any two readings on the same subject is expected to be between RC=±0.104 for 95% of participants, which correspond to 95% CI for LoA as shown in Table 4. The 95% confidence interval (CI) for the RC was {RC_L, RC_U}={0.088, 0.127}. To assess the level of repeatability of the measurements, it is suggested to use within-subject coefficient of variation, CV_W (x100%), which measures an (average) error rate. The CV_W is 3.7%, indicating a relative stability of the measurements at the subject level. The same was done for rightward rotations as presented in Table 3. The difference between any two readings on the same participant is expected to be between RC = ±0.103 for 95% of participants. The 95% confidence interval (CI) for the RC is {RC_L, RC_U} = {0.087, 0.125}. The within-subject coefficient of variation, CV_w, is also 3.7%, indicating a relative stability of the measurements at the subject level.

DISCUSSION

The aVOR gain measurement for session 1 ranged from 0.95-1.04. For session 2 the measurement ranged from 0.95-1.05, and 0.94-1.08 for session 3. McGarvie and colleagues found that across all ages the normative aVOR gain when testing the horizontal canal using vHIT was clustered closely around 1. The same was observed by Ross and Helminski who also measured a mean aVOR gain of 1.00-1.04. As demonstrated in figure 1 the mean gains measured in this study reflect the normative values observed by previous studies.[8,10] For all three sessions very low SD were obtained indicating that the data were closely clustered around the mean, confirming the aVOR gains measured were close to 1.

Regression analysis revealed that the slope was not statistically significant, indicating that no trend can be observed. The absence of a trend renders our analysis valid. The Bias analysis investigates a consistent difference observed on average, this too was not statistically significant indicating that no consistent bias was present. The 95% CI for LoA shows the differences between measurements; the differences seen were very small which shows clinically that even with the differences present between the measurements the participants will still present with results within the normal limits. The 95% CI for LoA and the 95% CI for RC are counterpart revealing that the differences measured were very similar for both methods of analysis (Table 4). To further show that the measurement repeated itself consistently the error rate was calculated. For both leftward and rightward rotations an error rate of 3.7% was computed indicating that the average deviations between measurements of the same participant were estimated at 3.7%. A good test-retest reliability can be deduced from the very small error rate (3.7%), indicating that the measurements repeated themselves consistently, as well as the small 95% CI for LoA and RC.

A challenge observed by other researchers is the lack of inherit neck stiffness in children, making it difficult to elicit responses greater than 100°/sec.[8,10] A head velocity during such an impulse, needs to be >100°/sec to show a present asymmetry in compensatory eye movements.[8] A head impulse delivered during a vHIT of <100°/sec is not considered a valid measurement, because some losses can still produce normal aVOR gain at such a low velocity.[10]

Therefore, it was recommended to use impulses with various velocities of >150°/sec during vHIT testing.[10] The crHIT protocol used in this study delivered impulses at 150°/sec and 160°/sec overcoming the challenge observed in the vHIT testing procedure for children.[8]

The crHIT can be used for children who are willing to participate and can follow instructions. For this study participants were shown a quick video on the test set up to help them be better prepared. As the testing procedure can be intimidating for a child, it is important to properly prepare them for what will happen. We observed the big role guardians play in the preparation of testing and the child's co-operation. Explaining to the children that they will feel like an astronaut during rotations made them very eager to participate. Being strapped in the rotary chair with their head held in place with head restraints, wearing heavy goggles and being inside a dark light proof booth can be very intimidating for a child. To our surprise, this only bothered one participant, who was scared of the dark. Most children mentioned that the test environment resembled a virtual reality game, and they were eager to get set up for the test. Every child was given a set of headphones with a microphone to reassure them that they could communicate with us and that at any time during the test their guardian was allowed in the booth if the child was scared. Modifications made for this study included strapping in a car booster seat for the smaller children to place their heads at the correct height for the head restraints. It was also communicated to the children just before a rotation, that they need to be ready and keep their eyes open. This preparation helped yield clear tracings with less blinking.

One can further investigate crHIT using a remote camera system instead of goggles to overcome the challenge of goggle slippage and testing children too small to have goggles mounted on their heads, as done in the vHIT.[9] Two-channel electrodes can also be used to record eye movements with the advantage that the child doen't need to keep their eyes open during testing, which is often difficult for smaller children.[18] These tracking cameras and electrodes are well known methods used for typical rotary chair testing to record eye movement as part of the pediatric vestibular test battery.[7]

Sinusoidal harmonic acceleration (SHA) testing forms part of the pediatric vestibular test battery to assess HSCC functioning at lower frequencies. Thus, if the child is already set up in the chair for testing the crHIT can be utilized as an ideal complimentary assessment for HSCC functioning at higher frequencies, where usually the vHIT would be used. This will save time in the overall test battery as the child doesn't need to be set up with a different pair of goggles and additional calibration will also not be required. The vHIT takes approximately 15 minutes to be completed, compared the crHIT that only takes between 1-2 minutes if the setup is already done for rotary chair testing.[19]

CONCLUSION

The cHIT is a reliable clinical tool in assessing HSCC functioning in the pediatric population as it is well tolerated by children and not dependent on examiner skills compared to the vHIT. The crHIT further overcomes some of the challenges of the vHIT by easily attaining head velocities greater than 100°/sec needed to detect asymmetries in milder losses. Adjustments can be made to make the testing procedure more child friendly while still yielding reliable results. Further studies are needed to investigate the specificity of the vHIT compared to that of the crHIT to determine whether it is feasible to use the crHIT instead of the vHIT or rather as an additional or complimentary test to assess HSCC functioning in children.

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