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

by

Nicole Mittendorf

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Supervisors:

Dr Barbara Heinze

Dr Alex Kiderman

Dr Jorge González

Ms Tarryn Reddy

Nicole Mittendorf

Department of Speech-Language Pathology and Audiology, University of Pretoria

nicole.mittendorf@gmail.com

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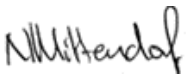

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Abstract

Objective: 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 the pediatric population.

Methods: To determine the test-retest 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 within 4 weeks in the following session. Each crHIT included two protocols: one using an earth-bound target and the other using a head-fixed target. The test-retest reliability was determined using a quantitative research approach with a repeated measures design.

Results: The mean aVOR gains for both stationary and suppression crHIT ranged from 0.93 – 1.01, with gains being lower for suppression compared to stationary crHIT. For stationary crHIT the ANOVA regression was not statistically significant for both leftward (within-session p=0.021 & between-session p=0.015) and rightward (within-session p=0.052 & between-session p=0.038) rotations, indicating no linear relationship between the differences and the averages, revealing a good test-retest reliability. For the suppression crHIT the regression of the differences was statistically significant for both leftward (within-session p=0.608 & between-session p=0.318) and rightward (within-session p=0.631 & between-session p=0.523) rotations. A positive relationship was observed for within-session and a negative relationship for between-session measurements. The suppression crHIT did not yield a good test-retest reliability, but the differences measured were smaller for between-session compared to within-session.

Conclusions: The stationary crHIT is a reliable clinical tool in assessing HSCC functioning in the pediatric population as it demonstrates good test-retest repeatability. Therefore, extending the pediatric vestibular test battery with crHIT can be a valuable diagnostic tool without adding to the overall test time. The suppression crHIT does not present with a good test-retest reliability due to the VOR inhibition reducing the gain with each impulse. Further research is needed to determine whether the statistically significant regression is clinically significant.

Key words: clinical tool, computerized head impulse test, horizontal semi-circular canal functioning, pediatric vestibular assessment, vestibular test battery

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List of Abbreviations

ANOVA	Analysis of Variance
aVOR	Angular Vestibulo-ocular Reflex
BPVC	Benign Paroxysmal Vertigo of Childhood
CW	Clockwise
CV_W	Coefficient of Variation
crHIT	Computerized Head Impulse Test
CCW	Counterclockwise
DAS	Developmental Assessment Schema
HIT	Head Impulse Test
HSCC	Horizontal semi-circular canal
LARP	Left Anterior and Right Posterior
LoA	Limits of Agreement
NOTC	Neuro-Otologic Test Centre
RALP	Right Anterior and Left Posterior
RC	Repeatability Coefficient
SHIMP	Suppression Head Impulse Test
VM	Vestibular Migraine
vHIT	Video Head Impulse Test
VOG	Video-oculography
VOR	Vestibulo-ocular Reflex

Chapter 1: Introduction

1.1 Background

The vestibular system involves key functions such as gaze stabilization, balance, postural orientation, and special navigation (Cohen & Keshner, 1989). Childhood vestibular disorders negatively impact intellectual and physical development. (Rogers, 2010; Gioacchini, Alicandri-Ciufelli, Kaleci, Magliulo, 2014). Vestibular dysfunction can alter spatial and non-spatial cognitive processes, delay gross and fine motor development and contribute to learning difficulties in school (Franco & Panhoca, 2008; De Kegel et al., 2012; Wiener-Vacher et al., 2013). Franco and Panhoca (2008) found a statistically significant association between children underperforming in school and vestibular alterations. A systematic review done by Gioacchini et al. (2014) 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 (BPVC) and vestibular migraine (VM) (Lee et al., 2017).

The vestibular system, along with vision and proprioception, all contribute to when a child learns to roll over, crawl, and then walk (Inoue et al., 2013). Vestibular mediated reflexes are present at birth (e.g., head righting response) (Adamović et al., 2020). It stands to reason that children with impairments that alter the vestibular reflexes are slower than their normal counterparts in reaching key milestones (Inoue et al., 2013). One of the primary vestibular reflexes is the vestibulo-ocular reflex (VOR). When a child with a normal vestibular system moves his or her head, the eyes reflexively deviate in the opposite direction so that the image is stabilized on the retina without blurring. This reflexive eye movement is called the VOR also referred to as the angular vestibulo-ocular reflex (aVOR). The aVOR is a vital reflex originating from the six semi-circular canals of the human vestibular sensory organ (Alhabib & Saliba, 2016). It involves three entities including the peripheral sensory apparatus (otolith organs and six semi-circular canals), central processing mechanism, and motor output (eye muscles) (Bronstein, Patel, & Arshad, 2014). The aVOR is triggered by fast head movements and responds by moving the eyes in the equal and opposite direction with the same velocity as the head to maintain gaze stability (Roy & Tomlinson, 2009).

The aVOR is tested using video-oculography (VOG) goggles to track eye movements during a physiological or non-physiological stimulation of the semi-circular canal. Testing of the aVOR has evolved over the years from caloric testing, rotary chair testing, bedside head impulse testing (HIT), and video head impulse testing (vHIT). The HIT is an ideal bedside assessment for detecting peripheral vestibular deficits (MacDougall, Weber et al., 2009). During the HIT, the examiner manually induces head rotations and directly observes for corrective eye movements after the impulse, also known as overt saccades (Furman etal., 2016). Weber et al. (2008) expanded on the HIT by using the scleral search coil method for a more objective measurement (Robinson, 1963). The scleral search coil method uses two scleral contact lenses which have a coil of wire embedded within them (Robinson, 1963). These lenses are worn by the patient while they are exposed to an alternating magnetic field (Robinson, 1963). The eye movements are then recorded using two magnetic fields in a quadrature phase, which generates a voltage within the coil (Robinson, 1963). During the study done by Weber et al. (2008) two types of saccades were observed, namely covert saccades at <100ms (occurring during head movement) and overt saccades at 150-250ms (occurring after head movement), which both hold valuable information for analysing the HIT results (Weber et al., 2008; Yacovino et al., 2018). Covert saccades are not noticeable by the naked eye, because it occurs during head movement, and can therefore lead to a wrong diagnosis when missed (MacDougall et al., 2009). Although the scleral search coil method yields reliable results, it is not clinically feasible, because it is time consumptive, expensive, and impractical for severe cases and the contact lens causes discomfort for the patient (MacDougall et al., 2009).

Caloric testing has long been a well-known part of the vestibular test battery for assessing the HSCC function in adults and children (Rodriguez & Janky, 2018). Caloric testing stimulates the aVOR by heating or cooling the endolymph within the semi-circular canal using air or water irrigation (Gonçalves, Felipe & Lima, 2008). The temperature change of the endolymph causes an artificial current, which bends the cupula resulting in an aVOR response (Gonçalves et al., 2008). This test, however, is not well tolerated by children because the air or water irrigation can cause dizziness in the case of normal HSSC functioning (Rodriguez & Janky, 2018). A further drawback to caloric testing is that it only assesses HSCC functioning at very low

frequencies using a non-physiological stimulus (Rodriguez & Janky, 2018). Rotary chair testing is also being used for children to assess their aVOR function by seating them on a rotary chair, often in a light proof booth, and measuring their eye movements while rotating the chair at different frequencies (Rodriguez & Janky, 2018). The two most common test protocols are the sinusoidal harmonic acceleration (SHA) and the step test, which assess the aVOR at different frequencies (Rodriguez & Janky, 2018). Rotary chair testing is child friendly as the child can sit on an adult's lap during rotations and the eyes can be monitored using VOG goggles or tracking cameras. However, during rotary chair testing right and left HSCC are stimulated together instead of separately. Rotational testing is therefore effective in identifying bilateral vestibular losses, but it does not provide a practitioner with information about the individual horizontal canals (Rodriguez & Janky, 2018). Over the last few years, the vHIT has become a valuable tool in assessing all six semi-circular canals individually at higher frequencies (Ross & Helminski, 2016). This test is well tolerated by children and can also be done using a remote camera system instead of goggles (Wiener-Vacher & Wiener, 2017). When specifically looking at the pediatric population, Ross and Helminski (2016) observed challenges in the vHIT system. Due to children's smaller physical features, such as smaller head sizes and smaller eyelid openings, measurement errors seem to occur more easily than in adults (Ross & Helminski, 2016). These measurement errors are caused by goggle slippage, excessive blinking, etc., resulting in artifacts and inaccurate aVOR gain recordings (Mantokoudis et al., 2014). Another downside is that the 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 (Ross & Helminski, 2016).

Furman and colleagues (2016) aimed to overcome the above-mentioned disadvantages, of needing an experienced examiner and having difficulty eliciting impulses greater than 100°/sec^2 due to the lack of inherent neck stiffness of the vHIT, by using the recently developed computerized rotational head impulse test (crHIT). To administer the crHIT, the system uses a rotary chair and a head mounted VOG system, that includes head tracking sensors and a target generating system. The same physiological principles govern the crHIT and the vHIT. A head turn displaces fluid

within the semi-circular canal, which causes the cupula to bend, eliciting the aVOR reflex, which then produces conjugate eye movements in the opposite direction of the head turn, resulting in gaze stability (Perez-Fernandez & Eza-Nuñez, 2015). By using the chair to induce the impulses, the crHIT uses complete body rotations whilst using VOG to record eye movements (Furman et al., 2016). These impulses are referred to as computerized because they are automated and not dependent on an examiner. The crHIT currently only allows for assessment of the HSCC of the human vestibular sensory organ. Continuous development of the crHIT is taking place to make testing of the vertical semi-circular canals possible. The vertical canals will be tested by placing the patient in the correct position for horizontal and vertical canal orientation in an earth horizontal plane as described in the patent published by Furman et al. (2020). However, research has only been done on assessing the horizontal semi-circular canals using the crHIT (Furman et al., 2016).

In the study done by Furman et al. (2016), the researchers found that the crHIT does not require a well-trained test administrator, unlike the vHIT. 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 the pseudo-random direction and magnitude of the turn (Furman et al., 2016). 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 (Furman et al., 2016; Ross & Helminski, 2016).

More recently MacDougall et al. (2016) investigated a modified version of the VHIT in which the target is head-fixed and not earth-bound. The suppression head impulse test (SHIMP) assesses vestibular functioning by eliciting anticompensatory saccades (MacDougall et al., 2016). The same physiological basis is used for the conventional head impulse test (HIT) as the SHIMP, therefore a similar aVOR gain is measured (Halmagyi et al., 2017). During the HIT the presence of covert saccades can cause

inaccurate gain measurements (Halmagyi et al., 2017). The SHIMP has the advantage that covert saccades are eliminated from the testing procedure yielding more reliable gain measurements, compared to the typical stationary target vHIT protocol (Halmagyi et al., 2017). Additionally, the size of the saccade can also be interpreted as an extra measure (Halmagyi et al., 2017). Nguyen et al. (2021) moreover investigated the reliability and functionality of the SHIMP in the pediatric population and concluded that it is a valuable addition to the pediatric vestibular test battery. Hence, the researchers deemed it valuable to include the suppression protocol of the crHIT in this study, as the test-retest reliability of the crHIT suppression protocol has not yet been investigated.

In summary, improved differential diagnoses are essential in guiding and improving intervention for the pediatric population, as intervention is dependent on the diagnosis made by healthcare professionals (Gedik-Soyuyuce et al., 2021). Gedik-Soyuyuce et al. (2021) emphasized the possibility of obtaining a more accurate diagnosis when using a multidisciplinary team and functional vestibular testing which has been adapted to be age-appropriate. It is important to continually update pediatric vestibular testing protocols and use evidence-based procedures to identify vestibular disorders accurately and reliably, as this will aid in preventing and overcoming the detrimental effects caused by childhood vestibular disorders (Rogers, 2010; Gedik- Gioacchini et al., 2014; Soyuyuce et al., 2021). 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 aid healthcare practitioners in making a more accurate diagnosis.

1.2 Study Rationale

Furman and colleagues (2016) showed the value of crHIT as part of the adult vestibular test battery; however, it remains unclear whether crHIT can be used reliably in the pediatric population. It is not yet known whether the crHIT will produce valid and

reliable responses in children and adolescents and presently the crHIT is not a recognized testing procedure for children. Hence, 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. The test-retest reliability was investigated for both earth-bound target (stationary crHIT) and head-fixed target (suppression crHIT) conditions.

1.3 Outline of Chapters

Chapter 1 describes the background and rationale of the study. This is followed by chapter 2 in which the method and ethical considerations are described in detail. The results of the suppression crHIT are portrayed in chapter 3. Chapter 4 contains the article submitted to the International Journal of Otorhinolaryngology and Head and Neck Surgery. Finally, chapter 5 contains the discussion, clinical implications, suggestions for further research, and conclusion. Additionally, the dissertation is concluded with a reference list and the appendices attached at the end.

Chapter 2: Methodology

2.1 Study Objectives

The aim of this study was to determine the test-retest reliability of the crHIT in typically developing children and adolescents. The test-retest reliability was investigated for both conditions using an earth-bound target (stationary) and a head-fixed target (suppression).

2.2 Research Design

To determine the test-retest reliability, the researcher used a quantitative research approach with repeated measures within subject design. This means that each participant acts as their own control to compare the retest results to (Sullivan, 2008).

2.3 Ethical Considerations

2.3.1 Ethical Clearance

Ethical clearance was applied for from the Research Ethics Committee of the Faculty of Humanities, University of Pretoria. Ethical approval (approval number: HUM022/1220) was obtained on 25 February 2021 (Appendix A). Data collection commenced once ethical approval was obtained.

2.3.2 Informed Consent

One parent or primary caregiver of each participant was required to complete and sign an informed consent letter (Appendix B). Each participant also had to provide written assent before participating in this study (Appendix C & D). The informed consent letter included the rationale and background of the study as well as a detailed explanation of the screening and testing procedure. The informed consent letter also informed the parent or legal guardian of the participant, of their child's right to withdraw from the study at any time, after which their data would be destroyed (Appendix B). To ensure that each participant understands what their participation in the study would entail, the researcher verbally explained the testing procedure in a simple manner also using the

pictures on the assent letter (Appendix C & D) in the participant's preferred language (English or Afrikaans). The participant could choose to receive their assent letter in English or Afrikaans. The participant was also shown a short video of the setup and testing procedure to inform them in a visual manner what the testing procedure would look like and what would be expected of them. Lastly, the child was asked to explain to the researcher in their own words what the study entails to ensure that they fully understand what they were agreeing to. A witness then had to sign off on the assent form, confirming that the participant understood what the study entailed.

2.3.3 Risks and Safety

The participants did not encounter any risks by participating in this study and did not experience any form of pain. However, mild discomfort from the VOG goggles and head fastenings was to be expected. The participants were securely fastened to the rotary chair with an adjustable harness attached to the rotary chair, to ensure their safety throughout the testing procedure. The head fastenings, which were used to keep the participant's head still during the chair rotations, were padded with a soft sponge to ensure comfort. When the chair rotated, the participant remained safely seated in the chair and moved with the chair during each rotation administer by the chair. The parent or legal guardian was allowed to be present inside the booth for emotional support, should the participant require it; however, that was not necessary during this study. The data collection took place in early 2021, during which time many people were still being infected with the COVID-19 virus. The researchers took specific precautions to ensure the safety of the participants, their guardians, and themselves from the COVID-19 virus. These precautions included sanitizing all equipment in-between sessions and, hand sanitizing and mask-wearing by everyone present, except when the participant was alone in the booth.

2.3.4 Confidentiality

The collected data is stored in an encrypted format. According to Leedy and Omrod (2010) human participants, participating in a research study have a right to privacy. Thus, the information gathered from each participant would not be made public. The

data collected from each participant was labelled with a code for analysis and when reporting on the results, to ensure confidentiality. During the data collection procedure, only the researcher and supervisors were aware of the participants' identities. During statistical analyses, only the alphanumeric codes of participants were available to ensure confidentiality.

2.3.5 Data Storage

The data collected is stored on a password-protected hard drive and is additionally stored in hard copy on a data collection sheet (Appendix F). The hard drive as well as the hard copies will be kept for 15 years in Room 3-11 at the Department of Speech-Language Pathology and Audiology, University of Pretoria. Additionally, the data will be stored on the University of Pretoria's international cloud-based Research Data Repository called Figshare.

2.4 Participants

To determine the number of participants required for the study, a repeated-measures analysis of variance design was done using the G*Power v3.1.9.4 software to conduct an priori power analysis. The assumed effect size of 0.8, as described by Cohen (1988), was used to establish any difference in the test-retest reliability of the crHIT at the power of 0.8. The priori power analysis determined that a minimum of 28 participants would be sufficient.

2.4.1 Sampling Strategy

Participants were recruited using a combination of convenience and snowball sampling. Family, friends, and acquaintances of researchers were contacted to recruit willing guardians and participants. These guardians and participants were then asked to recruit further willing participants.

2.4.2 Participant Selection Criteria

The participant exclusion criteria are explained in Table 1.

Table 1: Participant exclusion criteria

Exclusion Criteria	***Reasoning***
Participant Information Form	
Age group: <6 and >17 years	Participants were excluded from the study if they were younger than six years because they would be too small for the testing equipment, and therefore could not be tested. Participants older than 17 were excluded because the study aimed to look at the test-retest reliability in the pediatric population.
Competent in English or Afrikaans	Participants were excluded from the study if they were not competent in either English or Afrikaans. This was done to ensure that each participant would understand the verbal instructions given to them by the researcher.
Trauma or surgery to the ear, head, or neck	Surgery or trauma to the ear or head could have caused damage to the peripheral or central vestibular system, which could adversely influence the results of the study (Abolpour Moshizi et al., 2022). Should a participant experience any neck problems they were also excluded from the study. Although the crHIT is ideal for testing people with neck problems, compared to the vHIT, these participants were still excluded because the screening procedure to ensure normal functioning of the HSCC included vHIT.
Vestibular symptoms (off balance or dizzy)	Off balance and dizziness are common symptoms of vestibular pathology and could possibly be indicative of a present vestibular dysfunction (Jahn et al., 2011).
Hearing loss	Hearing loss is a common secondary symptom of vestibular disorders, therefore these participants were also excluded (Agrup, Gleeson, & Rudge, 2007).
Gross motor skills	Timely met gross motor skills are a good indicator of normal vestibular functioning. It has been observed that children who present with vestibular difficulties also exhibit delays in gross motor skills development (Inoue et al., 2013).
vHIT	
vHIT gain <0.8, presence of overt and/or covert saccades	A gain of less than 0.8 and the presence of overt and/or covert saccades indicates abnormal HSCC, and these participants were excluded (Perez-Fernandez & Eza-Nuñez, 2015).

The study aimed to include participants that were gender and age-matched to ensure that the entire population was equally represented. This meant that the researchers aimed to involve approximately 50% male participants and 50% female. To ensure equal age distribution of younger children and adolescents participants were divided into two age groups; children (8-12 years) and adolescents respectively (13-17 years) Researchers aimed to include an equal number of children and adolescents in the study.

2.4.3 Participant Selection Procedure

Willing participants were provided with an assent letter (Appendix C & D), and their parents were given an informed consent letter (Appendix B). The screening and testing procedures are explained in detail in the assent letter and the informed consent letter. These forms were signed by the participant and the parent or legal guardian before commencing the screening procedure.

Screening procedure:

Step 1: Information Form

The parents of the participants were given an information form (Appendix E) which included (1) the participant's information, (2) medical history questions relevant to prompt information regarding the exclusion criteria, and (3) a list of gross motor skills acquired at certain ages. The DAS (Developmental Assessment Schema) is a general developmental assessment scale which assesses multiple areas of development, including gross motor skills (Anderson, Nelson & Fowler, 1978). The DAS was used to determine typical development, specifically looking at timely met gross motor skills indicated by the participant's guardian.

Step 2: Video Head Impulse Test:

Participants underwent lateral vHIT as a screening procedure to ensure normal semi-circular canal functioning, evident by a gain greater than 0.8 and the absence of any convert and overt saccades (Perez-Fernandez & Eza-Nuñez, 2015). The ICS Impulse

system, with OTOsuite software (GN Otometrics, Taastrup, Denmark), was used for lateral vHIT testing. For the vHIT, the participant was seated in an upright position facing a wall, with a high-speed video system mounted onto a specialized set of VOG goggles, which was secured to their head. The participant was then instructed to focus their gaze on a target on the wall 2m away while the examiner induced manual head rotations of 15˚ with a peak velocity of > 150°/sec to the left and right (MacDougall et al., 2009). The manual head rotations were measured using the ICS Impulse System with VOG goggles. The ICS Impulse System only accepts head rotations with a head velocity of >150°/sec, ensuring that the researcher considered only good quality impulses for evaluation. Participants who attained a gain greater than or equal to 0.8 with no saccades present were included in the study.

The study included 29 typically developing children and adolescents with normal vestibular functioning, between the ages of 8-17 years (52% female). Participants had a mean age of 12.2 ± 2.7 years. An evenly balanced age distribution was also achieved as the participants consisted of 13 children between 8-12 years (45%) and 16 adolescents between 13-17 years (55%).

2.5 Equipment and Apparatus

All test procedures for the screening and data collection were done at the Department of Speech-Language Pathology and Audiology at the University of Pretoria. For the data collection procedure, the following equipment was used:

- Neuro-Otologic Test Centre (NOTC), Neurolign LLC (Pittsburgh, PA; USA)
- VEST (TM) video-oculography software (Version 8.2), Neurolign LLC, (Pittsburgh, PA; USA)
- Light proof booth (model no. RCS-035), Neurolign LLC, (Pittsburgh, PA; USA)

The crHIT was conducted in 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. Additionally, the chair included cushioned head restraints to keep the participant's head still and safety straps to keep the participant safely in the chair during rotations.

2.6 Data Collection Procedures

2.6.1 Test Setup

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 so the head restraints could be properly applied. The test setup in the rotary chair is shown in Figure 1.

Figure 1: Displaying an 8-year-old female participant securely strapped in the rotary chair (written consent was obtained from the mother of the child to use her photo in the dissertation – see Appendix G)

2.6.2 Testing Procedure

Every participant underwent three crHIT assessments. The crHIT assessment 1 and 2 were conducted within the same session, to obtain within-session reliability and the crHIT assessment 3 was conducted within approximately 4 weeks of the first session, to obtain between-session reliability. The time interval between tests was scheduled according to each participant's availability. For the test procedure, 12 uninterrupted whole-body rotations took place in 6 clockwise (CW) and 6 counterclockwise (CCW) directions through abrupt random accelerations delivered from the rotary chair. The accelerations differed from 999°/sec^2 to 1066°/sec^2, with each acceleration followed by a gradual deceleration to a stop at a rate of 150°/sec^2 to 200°/sec^2.

Each crHIT assessment included two protocols:

- Protocol 1 – utilized an earth-bound target (stationary crHIT)
- Protocol 2 – utilized a head-fixed target (suppression crHIT)

The two different protocols were used to determine the direction (CW/CCW), velocity, and the number of accelerations (Table 2). The participant and equipment were inspected and readjusted in between each protocol to ensure that their head was still securely fastened and that the goggles had not shifted. To prevent the learning effect, participants were also assigned a random order of the two protocols for each assessment.

Table 2: crHIT Accelerations and Peak Velocities for Protocol 1 and 2

	Protocol 1: Earth-bound Target		**Protocol 2: Head-fixed Target**	
Impulse	*Acceleration (˚/sec^2)*	*Peak velocity (˚/sec)*	*Acceleration (˚/sec^2)*	*Peak velocity (˚/sec)*
1	160	1065.7	160	1065.7
2	-150	-999.1	-150	-999.1
3	-160	-1065.7	-160	-1065.7
4	160	1065.7	160	1065.7
5	150	999.1	150	999.1
6	-150	-999.1	-150	-999.1
7	-160	-1065.7	-160	-1065.7
8	-150	-999.1	-150	-999.1
9	160	1065.7	160	1065.7
10	150	999.1	150	999.1
11	-160	-1065.7	-160	-1065.7
12	150	-999.1	150	-999.1

*Note: Positive values indicate CW direction and negative values indicate CCW direction of rotation.

At the beginning of every crHIT assessment calibration was done to ensure accurate eye movement recordings. For the calibration procedure, the participant was instructed to keep their gaze on the red laser target in front of them. The target then moved from left to right, followed by up and down. Calibration was then sometimes repeated between protocols 1 and 2 if goggles had slipped and the researcher had to readjust them for the next protocol.

Protocol 1: Earth-bound Target (stationary crHIT):

For protocol 1 the participant was instructed to keep their eyes on the red laser target in front of them for as long as possible. The red laser target was projected onto the booth wall 1m away from the participant. The target was earth-bound meaning that it remained stationary while the chair would rotate in a CW or CCW direction. Figure 2 depicts a screenshot of a crHIT tracing in a CCW direction, measuring the function of the left HSCC. The black line represents the chair rotation, and the red line indicates the recorded eye movement.

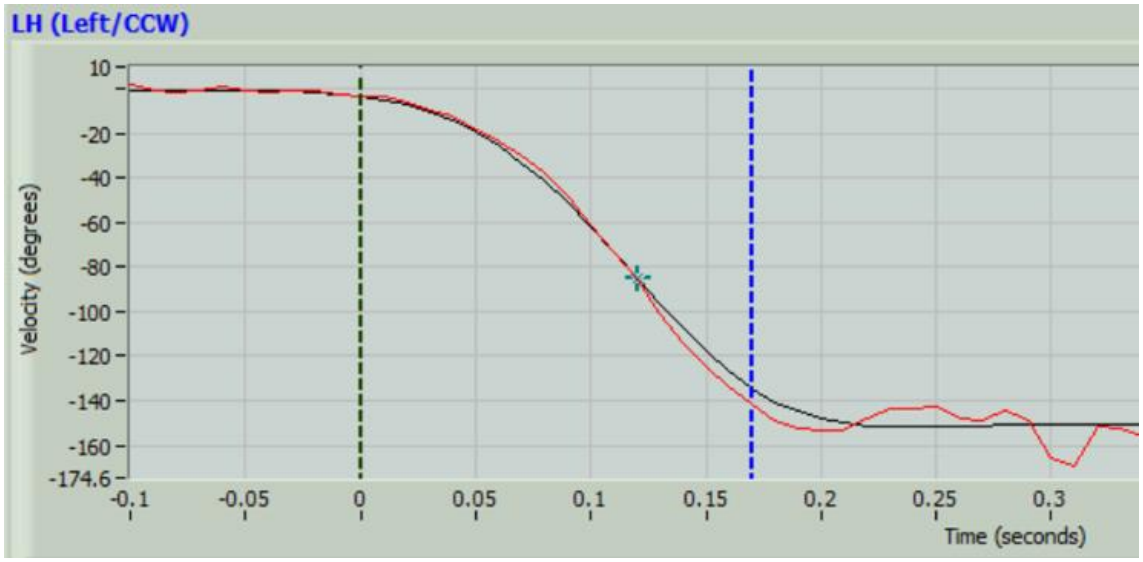


Figure 2: Displaying a reliable crHIT tracing in a CCW direction using an earth-bound target

Protocol 2: Head-fixed Target (suppression crHIT):

For protocol 2 the participant was instructed to follow the target with their gaze while they rotated. The red laser target was also shone against the booth wall 1m away from the participant. For this protocol the target was head-fixed. The red laser target moved together with the chair staying in front of the participant during the entire rotation, instead of staying stationary as in protocol 1. Figure 3 depicts a screenshot of a reliable tracing of an impulse for the suppression crHIT. As in Figure 2, the black line represents the chair rotation, and the red line represents the recorded eye movement. The head-fixed target elicits an aVOR cancellation response (Halmagyi et al., 2017). As seen in Figure 3 the aVOR is initiated, but then the gain starts to decrease compared to the velocity of the chair as the vision takes over and suppression takes place, resulting in a saccade at 0.16 seconds.

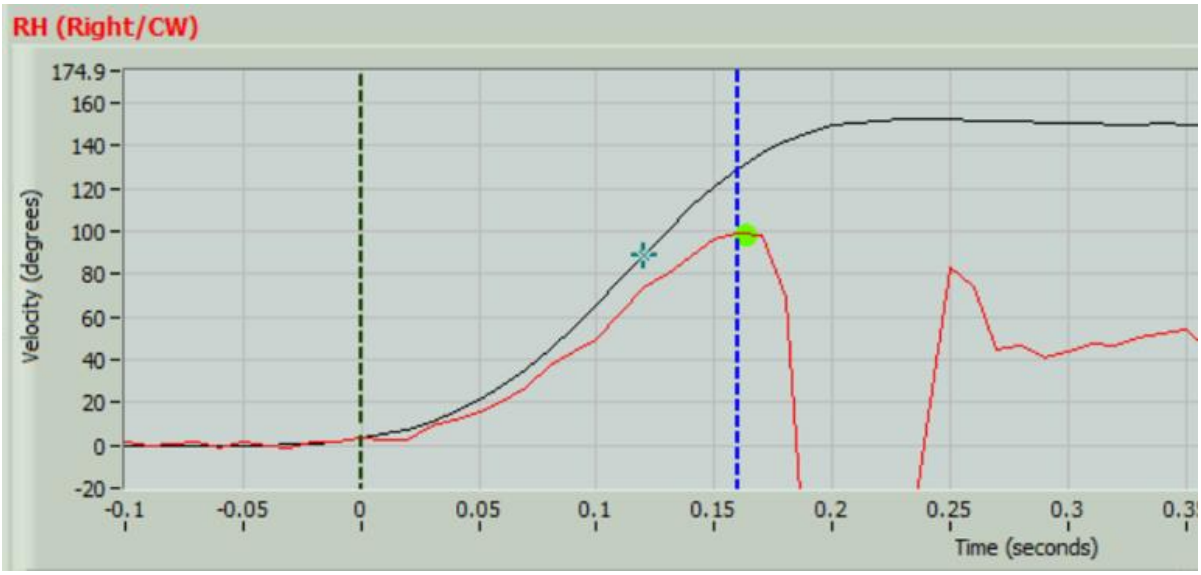


Figure 3: Displaying a reliable crHIT tracing in a CW direction using a head-fixed target

When interpreting the crHIT results, a gain >0.8 and absent saccades are expected for normal semi-circular canal functioning.

The crHIT setup for a test session took 5-10 minutes depending on the age of the child. For older children, the setup was faster than for younger children. The calibration of the VOG goggles took about 45sec. Each protocol took 1-2 minutes to complete all 12 impulses. Finally, unstrapping the participant and removing all the equipment off

took another 2 minutes. On average doing one crHIT assessment with both protocols took between 15-20 minutes, including giving instructions and reassurance in between. The researcher reassured the younger participants during the testing procedure. Between each protocol and calibration, the booth was opened, and it was ensured that the child was coping and was still willing to continue. It was during these times that the researchers also checked if the goggles and head restraints were still in place.

As the data collection took place during the COVID-19 pandemic special care was taken to comply with the rules and legislation as set out by the government of South Africa. Masks were worn the entire time by both the examiner and participant as well as the accompanying parent or guardian and regular hand sanitation was adhered to by all. The participant was only allowed to remove their mask during the testing procedure when they were alone in the closed booth. All equipment used was sanitized before and after each test session.

2.6.3 Validity and Reliability:

To ensure valid and reliable data it was ensured that all participants had met their gross motor milestones according to typical development laid out by the DAS. Normal HSCC function was further confirmed by vHIT screening to ensure that data was only collected from normally developing children and adolescents with normal HSCC function. The crHIT induces small abrupt movements during which the goggles could slightly slip and the head fastenings could loosen. The researcher therefore rechecked the goggles and refastened them between each test to ensure the validity and reliability of external factors during the testing procedure.

2.7 Data Analysis

Data analysis was conducted using Microsoft Excel and the statistical software program IBM SPSS (version 28) to perform descriptive and inferential statistics. For each participant, the crHIT session 1 and session 2 were utilized to assess within-

session reliability and the crHIT session 2 and session 3 were compared to assess between-session reliability. The same analysis was done for both protocols. The Shapiro-Wilk Test of Normality revealed a normal distribution of the data, therefore parametric statistical tests were used (Yap & Sim, 2011). For this study the one-way repeated measure Analysis of Variance (ANOVA) was used to test for a statistically significant difference between the within-session crHIT assessments and the between-session crHIT assessments, indicating the presence or absence of linear relationships between differences and averages.

ANOVA Analysis:

- Null Hypothesize = There is no linear relationship between the differences and averages
- Alternative Hypothesize = There is a linear relationship between differences and averages

For this study, the null hypothesis was accepted if the *p*-value is > 0.05. The same will apply to the bias analysis.

Next, the Limits of Agreement (LoA) Method and the Repeatability Coefficient (RC) were utilized for assessing consistency in measurements within-sessions and between-sessions (Bland & Altman, 1986; Bland & Altman, 1999; Barnhart & Barboriak, 2009). For the LoA Method, the mean difference was calculated using the t-test to determine possible present bias.

Bias Analysis:

- Null Hypothesize = There is no bias
- Alternative Hypothesize = There is a possible bias

Thereafter the LoAs was calculated for the average of the differences. Additionally, the upper and lower limit 95% confidence intervals (CI) were determined. To confirm the LoA tested the RC were 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.

Chapter 3: Results for Suppression crHIT

The same analysis was done for the stationary and suppression crHIT. In this chapter, the results are only depicted for the suppression crHIT. The results for the stationary crHIT are portrayed in detail in the article in chapter 4. The gain results are presented first followed by the regression analysis results. Lastly, the LoA and thereafter the RC results are presented.

For two participants data was only used for test sessions 1 and 2. One participant was unable to attend the third session and the other had excessive eye blinks during session 3, therefore the data had to be omitted from the between-session analysis. Additionally, another four sessions had to be omitted from the analysis due to artifacts causing unreliable recordings. In total six sessions had to be omitted, in other words for six participants, one session for each participant was excluded from the study.

The mean aVOR gains measured for session 1 was 0.94, for session 2 it was 0.93 and for session 3 it was 0.94. The standard deviations (SD) measured were 0.164 (session 1), 0.177 (session 2), and 0.139 (session 3). The aVOR gain results obtained for each participant during each testing session for right and left rotations combined are graphically depicted in Figure 4.

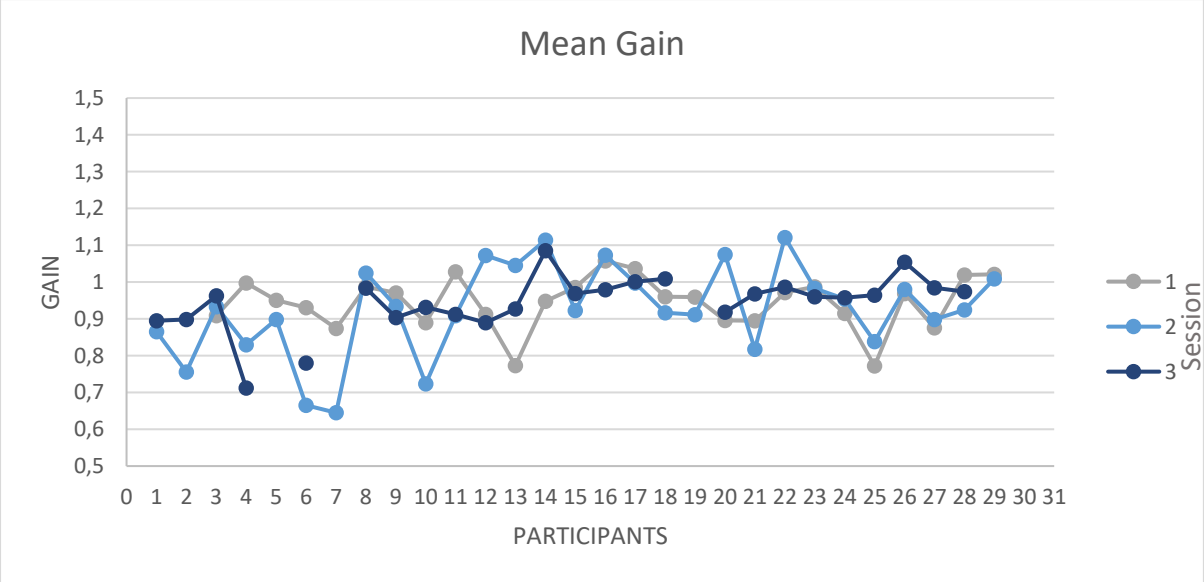


Figure 4: Mean gain. Points represent the mean gains of each participant for sessions 1, 2 and 3 for the head-fixed target condition

The results shown are presented for crHIT gain outputs for the head-fixed target condition. Since each participant's HSCC function was measured three times, the statistics are presented using the Bland-Altman plot separately for measurement 1 vs. 2 (within-session) and measurement 2 vs. 3 (between-session). In addition, using an RC and the corresponding statistics, we refer to all three measurements together again (Barnhart & Barboriak, 2009).

3.1 Regression Analysis

The one-way repeated measures ANOVA revealed that the crHIT leftward rotations were statistically significant, for the with-in sessions (p=0.021) and between-sessions (p=0.015), indicating that there is a linear relationship between the differences and the averages. Interestingly, the relationship is positive in the case of within-session and negative between-session. The positive relationship observed within-session indicated larger differences between gains. For between-session, the negative relationship indicates smaller differences implying better repeatability compared to within-session measurements. The regression of the differences on the average (slope) was also statistically significant for the rightward rotations when comparing the first two sessions (p=0.052) and between the last two sessions (p=0.038), indicating that there is a linear relationship between the differences and the averages. For rightward rotations, a similar positive relationship for the case within-session and a negative relationship for between-session was observed. The bias computation was taken directly from the differences; however, this finding somewhat complicated the analysis of bias below.

3.2 LoA Method

3.2.1 Bias Analysis

For this study, as mentioned above the 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*=0.855) and between-session (*p*=0.889), 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*=0.576) and between-session (*p*=0.393), also revealed no evidence of bias. Although these results indicate no evidence of bias the result needs to be treated with some caution.

3.2.2 Limits of Agreement

The standard deviation of the differences was used in the computation of the limits of agreement for the earth-bound target condition. For leftward rotations, the 95% LoA interval for within-session was -0.329 (lower limit) and 0.317 (upper limit) and for between-session -0.244 (lower limit) and 0.237 (upper limit). For rightward rotations, the 95% LoA interval for within-session was -0.274 (lower limit) and 0.245 (upper limit) and for between-session -0.226 (lower limit) and 0.271 (upper limit). The LoA is graphically depicted in the Bland-Altman plot for within-session (1 vs 2) and between-sessions (2 vs 3) (Figure 5 and Figure 6, respectively). Additionally, the lower and upper CI of the LoA were calculated and presented in Table 3.

Table 3. CI for lower and upper LoA for suppression crHIT

	Leftward rotations				Rightward rotations			
Session	**95% CI for the Lower LoA**		**95% CI for the Upper LoA**		**95% CI for the Lower LoA**		**95% CI for the Upper LoA**	
	Lower	**Upper**	**Lower**	**Upper**	**Lower**	**Upper**	**Lower**	**Upper**
1 vs 2	-0.442	-0.216	0.204	0.430	-0.364	-0.183	0.154	0.335
2 vs 3	-0.332	-0.156	0.149	0.325	-0.317	-0.136	0.180	0.361

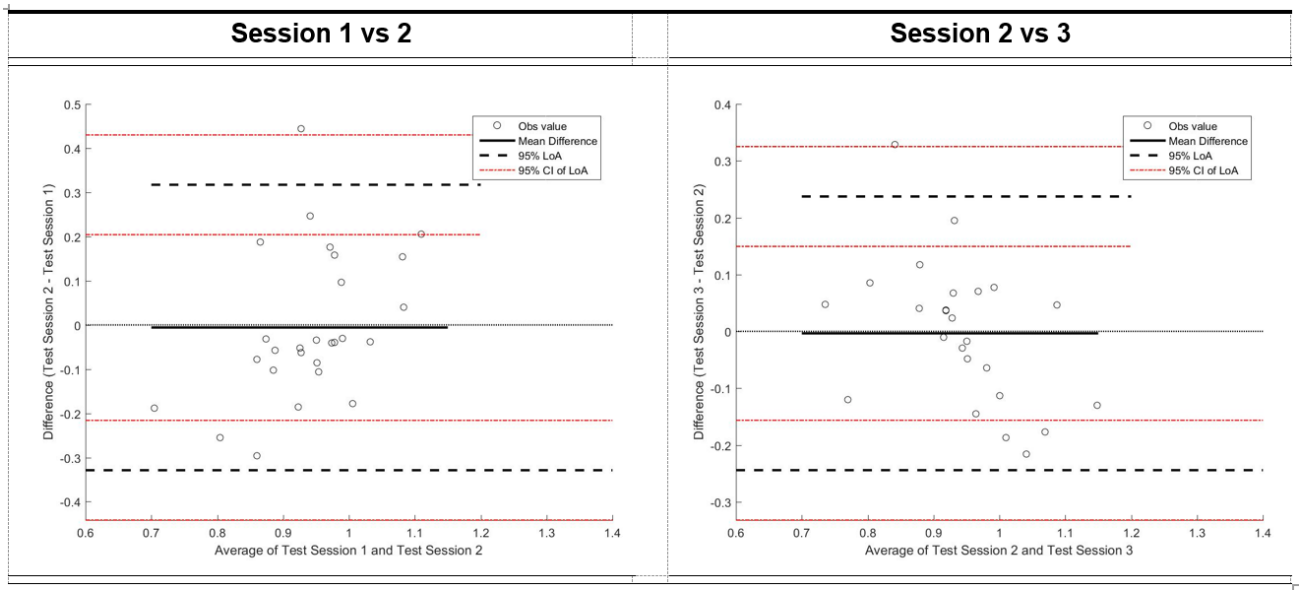


Figure 5: Bland-Altman plot (leftward rotations) for suppression crHIT

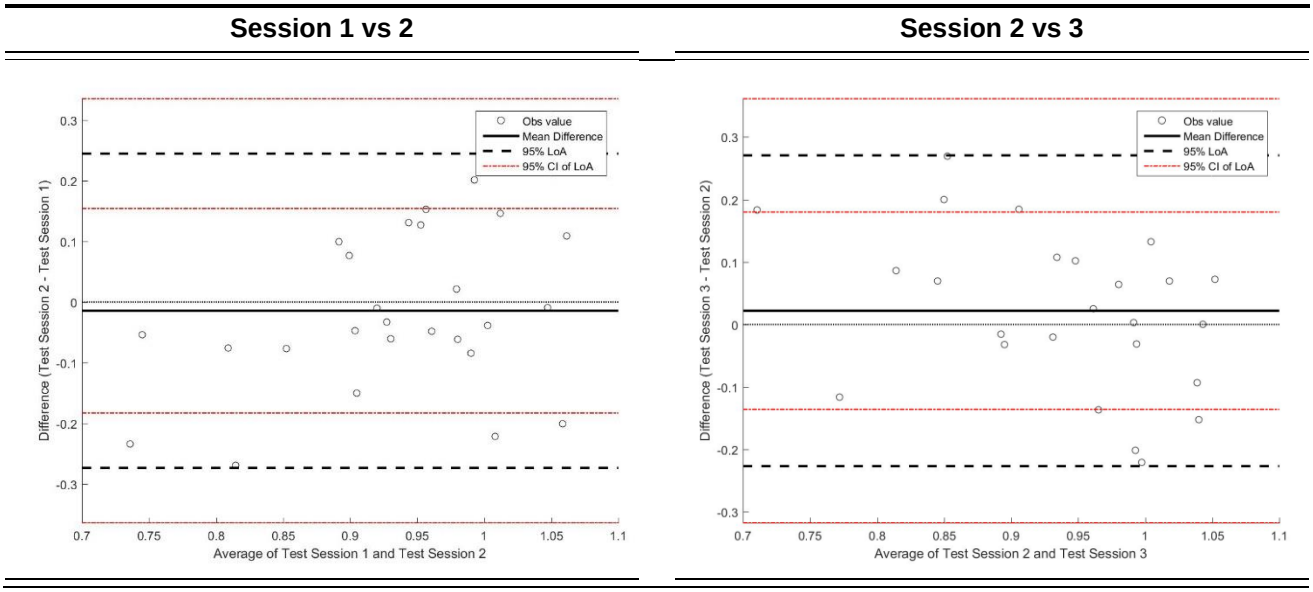


Figure 6: Bland-Altman plot (rightward rotations) for suppression crHIT

3.3 RC Method

The RC was calculated using all three measurements as presented in Table 4, as done for the earth-bound target condition. 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 = ±0.279 for 95% of participants, which corresponds to 95% CI for LoA as shown in Table 20. The 95% confidence interval (CI) for the RC was {RC_L, RC_U} = {0.236, 0.340}. To assess the level of repeatability of the measurements, it is suggested to use the within-subject coefficient of variation (CV_W) (x100%), which measures an (average) error rate. The CV_W is 10.7%, which indicates that the relative difference (%) of the measurements exceeds that of the earth-bound target crHIT test (3.7%), but it is still not a very unusual error.

The same was done for rightward rotations as presented in Table 5. The difference between any two readings on the same participant is expected to be between RC = ±0.245 for 95% of participants. The 95% confidence interval (CI) for the RC is {RC_L, RC_U} = {0.208, 0.300}. The within-subject coefficient of variation, CV_w is also 9.5%, indicating relative stability of the measurements at the subject level.

Table 4. The within-subject variance and repeatability coefficient (leftward rotations) for suppression crHIT

Number of sessions (K)	Sq. root of within-subject variance			Repeatability coefficient			Error rate
		95% CI for σ_w			95% CI for RC		$CV_w = \sigma_w/\mu$
	$\widehat{\sigma}_w$	$\widehat{\sigma}_{w,L}$	$\widehat{\sigma}_{w,U}$	$\widehat{RC}$	RC_L	RC_U	
3	0.101	0.085	0.123	±0.279	0.236	0.340	10.7%

Table 5. The within-subject variance and repeatability coefficient (rightward rotations) for suppression crHIT

Number of sessions (K)	Sq. root of within-subject variance			Repeatability coefficient			Error rate
		95% CI for σ_w			95% CI for RC		$CV_w = \sigma_w/\mu$
	$\widehat{\sigma}_w$	$\widehat{\sigma}_{w,L}$	$\widehat{\sigma}_{w,U}$	$\widehat{RC}$	RC_L	RC_U	
3	0.088	0.075	0.108	±0.245	0.208	0.300	9.5%

Table 6. Comparing 95% CI for LoA with 95% CI for RC for suppression crHIT

	Leftward rotations				Rightward rotations			
Session	**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	-0.329	0.317	0.236	0.340	-0.274	0.245	0.208	0.300
2 vs 3	-0.244	0.237			-0.226	0.271		

*lower and upper limits for all three sessions combined

Within one session the gain seemed to decrease with every impulse administered to the participant (Figure 7). The same downward pattern was observed between-session, where the gain also seemed to decrease with each session. This was more pronounced in some participants than others.

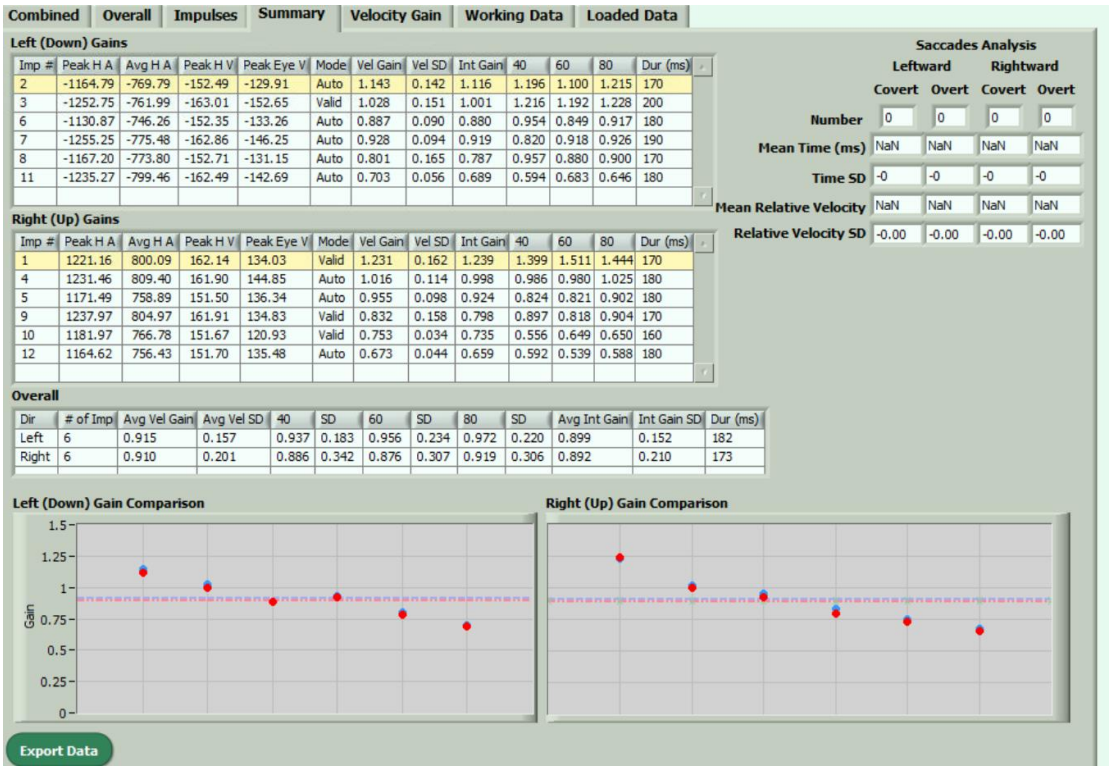


Figure 7: Recording of head-fixed target crHIT on NOCT software, showing the downward slope of gain with each impulse.

Chapter 4: Article

Test-retest Reliability of the Computerized Rotational Head Impulse Test in the Pediatric Population

Authors: Nicole Mittendorf, Tarryn Marisca Reddy, Barbara Heinze, Alex Kiderman, Jorge González

Journal: International Journal of Otorhinolaryngology and Head and Neck Surgery (IJOHNS)

Submitted: 27 September 2022

Status: In Review

The article was written according to the specifications of the journal and therefore the referencing and format differ from that of the dissertation. The journal required in-text number referencing, which was replaced with APA 7th edition in-text referencing to eliminate an additional reference list.

4.1 Abstract

Objective:

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 the 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 evident 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 for 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.

Key words: clinical tool, computerized head impulse test, horizontal semi-circular canal functioning, pediatric vestibular assessment, vestibular test battery.

4.2 Introduction

Childhood vestibular disorders negatively affect intellectual and physical development, as they can cause learning difficulties, delays in gross motor skills and spatial problems (Rogers, 2010; Gioacchini et al., 2014). 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 (O'Reilly et al., 2010; Rogers, 2010; Gioacchini et al., 2014). A systematic review done by Gioacchini and colleagues (2014) 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 (Lee et al., 2017). 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 as well as the financial impact of such expensive scans (Wiener-Vacher, 2008). Such a child must first undergo a full oto-neuro-vestibular clinical examination, an ophthalmologic examination, and an audiovestibular examination, unless neurological symptoms are present (Wiener-Vacher, 2008).

Better differential diagnoses are essential in guiding and improving intervention for these children, as intervention is dependent on the diagnosis made by health care

professionals (Gedik-Soyuyuce et al., 2021). Gedik-Soyuyuce and colleagues 2021 emphasized the possibility of obtaining a more accurate diagnosis when using a multidisciplinary team and functional vestibular testing which has been adapted to be age-appropriate. Rodriguez and Janky 2018 further looked at using quantitative semi-circular canal tests including video head impulse testing (vHIT), rotary chair testing, and caloric testing for certain ages and explained which modifications can be made to make the tests more child friendly.

Caloric testing has long been the highest standard for assessing the HSCC functioning in adults and children (Rodriguez & Janky, 2018). This test, however, is not well tolerated by children because the air or water irrigation can cause dizziness (Rodriguez & Janky, 2018). A further drawback to caloric testing is that it only assesses canal functioning at low frequencies using a non-physiological stimulus (Rodriguez & Janky, 2018). Rotary chair testing is also 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 video-oculography (VOG) 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 doesn't provide a practitioner with information about the individual canals (Rodriguez & Janky, 2018).

Over the last few years, the vHIT has become a great tool in assessing individual HSCC at higher frequencies (Ross & Helminski, 2016). This test is very well tolerated by children and can also be done using a remote camera system instead of goggles (Wiener-Vacher & Wiener, 2017). When specifically looking at the pediatric population, Ross and Helminski (2016) observed challenges in the vHIT system. 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 (Ross & Helminski, 2016). Another downside is that the 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 (Ross & Helminski, 2016).

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 (Ross & Helminski, 2016). In some patients the aVOR gain may seem normal when using slower impulses; however, when the peak head impulse velocity is increased, the loss is more evident (McGarvie et al., 2015).

Furman and colleagues (2016) 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). To administer crHIT, the system uses a rotary chair and a head mounted VOG goggles that includes head tracking sensors and a target generating system. The same physiological principles are applied with the crHIT as those that pertain to the vHIT. These physiological principles imply that a natural stimulus, head rotation, is used to evoke the aVOR generating a corrective eye movement (Halmagyi et al., 2017). By using the chair to induce these impulses, the crHIT uses whole body rotations whilst the VOG records the eye movements (Furman et al., 2016). These automated impulses are referred to as computerized because they are not dependent on an examiner.

Furman and colleagues (2016) found that the crHIT does not require a well-trained test administrator, unlike the vHIT. The crHIT also requires a smaller number of impulses, since each impulse is accurately and specifically defined and provides more patient comfort, compared to the vHIT. Furthermore, the crHIT prohibits prediction from the patient, because of the pseudo-random direction and magnitude of the turn (Furman et al., 2016). 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 required to identify the asymmetry in compensatory eye movements (Furman et al., 2016; Ross & Helminski, 2016).

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 performed reliably. This could further aid healthcare practitioners in making a more accurate diagnosis. As seen in the study by Ross and Helminski (2016) we also hypothesize that the aVOR gain will not be influenced by age. 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.

4.3 Method

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 the participants' legal guardians and written informed assent was 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 (Anderson, Nelson & Fowler, 1978).

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 (Perez-Fernandez & Eza-Nuñez, 2015).

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) was used to test for linear relationship between differences and averages. Next, the Limits of Agreement (LoA) Method and the Repeatability Coefficient (RC) were utilized for assessing consistency in measurements within-sessions and between-sessions (Bland & Altman, 1986; Bland & Altman, 1999; Barnhart & Barboriak, 2009). 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.

4.4 Results

Participants had a mean age of 12.2 ± 2.7years (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 (Fig. 8). The standard deviations (SD) measured were 0.030 (session 1), 0.031 (session 2) and 0.036 (session 3).

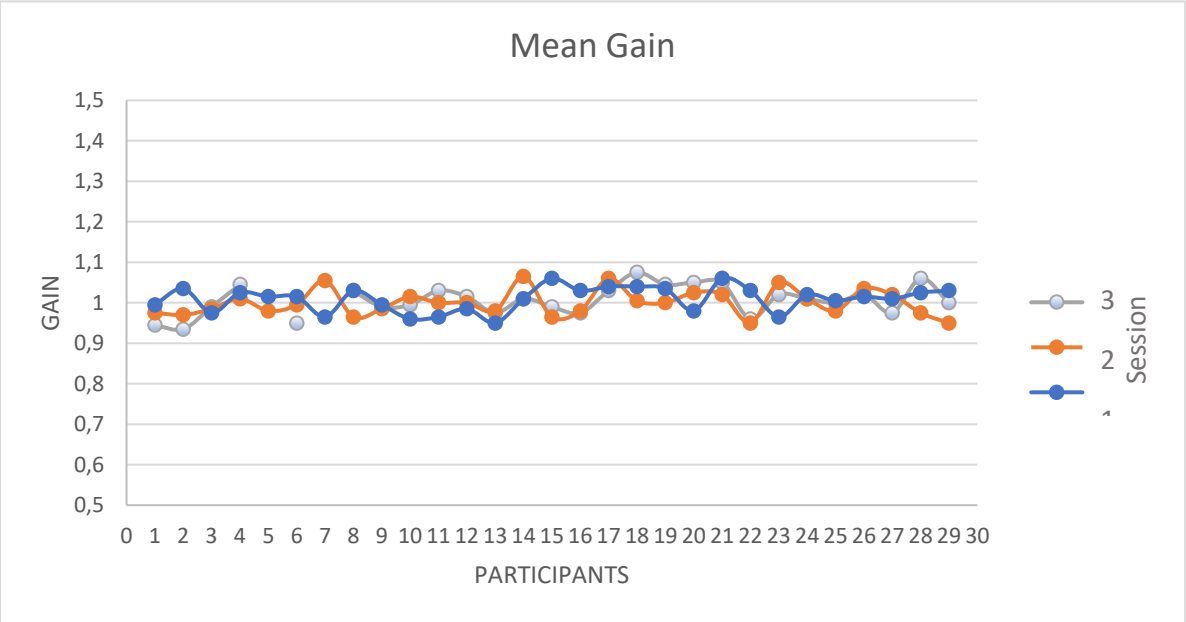


Figure 8: Mean gain. Points represent mean gains of each participant for session 1,2 and 3

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 RC and the corresponding statistics, we refer to all three measurements together (Barnhart & Barboriak, 2009).

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) (Fig. 9 and Fig. 10, respectively). Additionally, the lower and upper CI of the LoA were calculated and are presented in Table 7.

Table 7. CI for lower and upper LoA for stationary crHIT

	Leftward rotations				Rightward rotations			
Session	**95% CI for the Lower LoA**		**95% CI for the Upper LoA**		**95% CI for the Lower LoA**		**95% CI for the 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

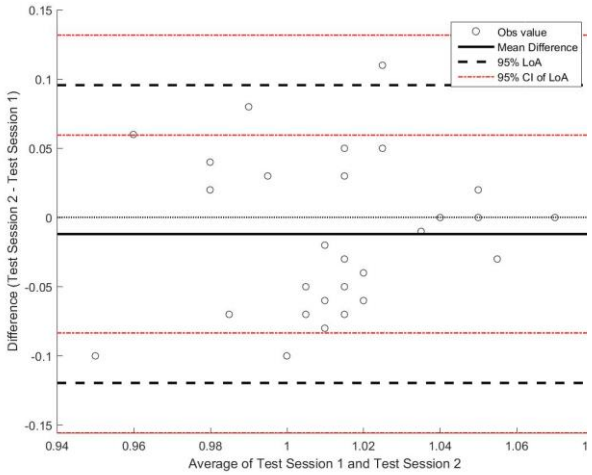
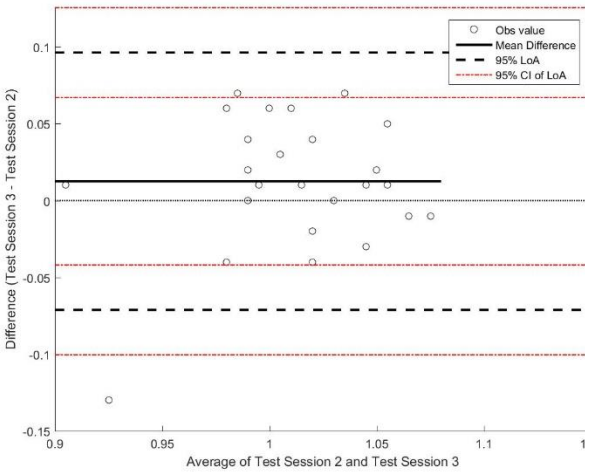
Session 1 vs 2	**Session 2 vs 3**
	

Fig. 9. Bland-Altman plot (leftward rotations) for stationary crHIT

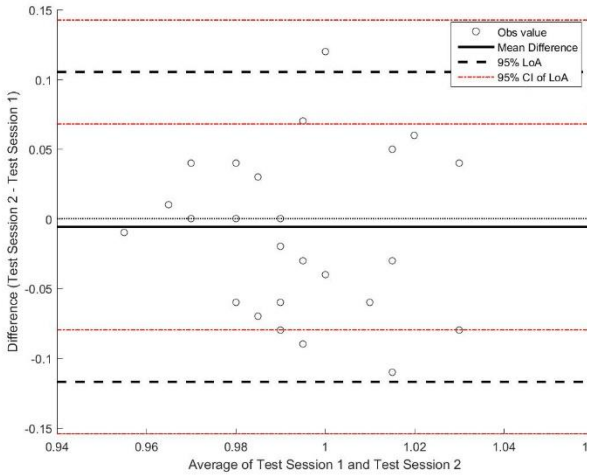
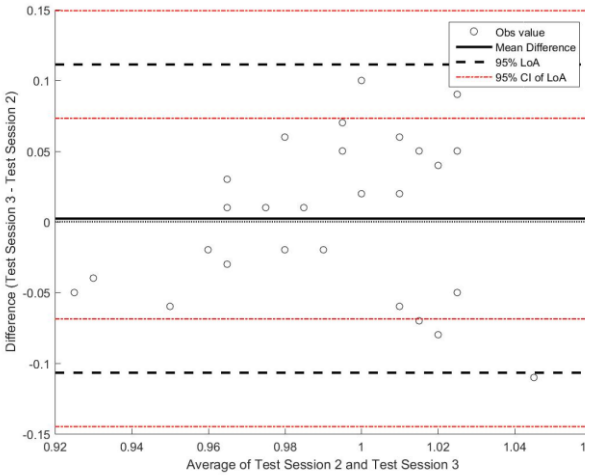
Session 1 vs 2	**Session 2 vs 3**
	

Fig. 10. Bland-Altman plot (rightward rotations) for stationary crHIT

RC Method

The RC was calculated using all three measurements as presented in Table 8. For leftward rotations a RC= ±0.104 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 6. 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 9. 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.

Table 8. The within-subject variance and repeatability coefficient (leftward rotations) for stationary crHIT

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

Table 9. The within-subject variance and repeatability coefficient (rightward rotations) for stationary crHIT

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

Table 10. Comparing 95% CI for LoA with 95% CI for RC for stationary crHIT

	Leftward rotations				Rightward rotations			
Session	**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

4.5 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 (McGarvie et al., 2015) 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 (2016) 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 in previous studies (McGarvie et al., 2015; Ross & Helminski, 2016). 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 (McGarvie et al., 2015; Ross & Helminski, 2016). A head velocity during such an impulse, needs to be >100°/sec to show a present asymmetry in compensatory eye movements (Ross & Helminski, 2016). 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 (McGarvie et al., 2015). Therefore, it was recommended to use impulses with various velocities of >150°/sec during vHIT testing (McGarvie et al., 2015). 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 (Ross & Helminski, 2016).

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 VOG 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 needed 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 VOG goggles to overcome the challenge of goggle slippage and testing children too small for goggles to be mounted on their heads, as done in the vHIT (Wiener-Vacher & Wiener, 2017). Two-channel electrodes can also be used to record eye movements with the advantage that the child doesn't need to keep their eyes open during testing, which is often difficult for smaller children (Janky & Patterson, 2020). 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 (Rodriguez & Janky, 2018). 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 VOG 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 (MacDougall et al., 2013).

4.6 Conclusion

The cHIT is a reliable clinical tool for 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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Chapter 5: Discussion, Clinical Implications, and Conclusion

5.1 Discussion for Suppression crHIT

The SHIMP protocol in vHIT testing is considered a valuable addition to the pediatric vestibular test battery (Nguyen et al., 2021). A few studies have investigated SHIMP, however, none have looked at the test-retest reliability in adults or in children. Nguyen et al. (2021) looked at using SHIMP for children and concluded that it has a high tolerance and can be used for children between the age of 3-18 years. The suppression crHIT presented with lower gains compared to the stationary crHIT. Rey-Martinez et al. (2018) observed statistically significant lower gain values (range: 0.74 – 1.04) for the SHIMP compared to the HIT as noted in this study which measured very similar aVOR gains and also observed lower gains for the suppression crHIT compared to those of the stationary crHIT. A further study compared the HIT and SHIMP in the diagnosis of bilateral vestibulopathy and also found a decreased gain for SHIMP compared to HIT (van Dooren et al., 2022). Very similar SHIMP mean gains of 0.98 and 0.94 were measured by Nguyen et al. (2021) in their pediatric sample as in this study.

A few studies have investigated SHIMP, but no studies have been done on the test-retest reliability of the SHIMP protocol in adults or in children. The same analysis was done to determine the test-retest reliability of the suppression crHIT. However, results contrasted somewhat with those obtained for the stationary crHIT. For within-session, a positive trend was seen for both leftward and rightward rotations and for between-session a negative trend. The positive trend observed for within-sessions implied the presence of larger differences. The negative trend between between-sessions suggested the presence of smaller differences compared to the within-session differences. From the regression present for both within-sessions and between-sessions, it can be concluded that the suppression crHIT does not yield good test-retest reliability. The bias analysis was not statistically significant, revealing no evidence of bias. However, these results need to be treated with some caution as a trend was observed in the regression analysis.

The LoA and RC were additionally calculated to measure the present differences between measurements. The LoA were presented in a Bland Altman plot to estimate an agreement interval (Giavarina, 2015). The 95% CI for LoA show the differences between measurements in Figure 5 and 6. The differences seen were larger than for the stationary crHIT, but still relatively small which shows clinically that even with the differences present between the measurements the participants will still present with results ranging from normative values to a slightly reduced aVOR gain as observed by Rey-Martinez et al. (2018). The 95% CI for LoA and the 95% CI for RC are strikingly similar for both methods of analysis (Table 6). In addition, we should note that the observed difference does not necessarily indicate that the difference is clinically significant. To further clarify whether the measurement repeated itself consistently the error rate was calculated. The error rate is still relatively small, and one could argue that clinically it can be deduced as relatively good test-retest reliability. Additionally, one could also argue that the differences are larger because the population consisted of children and that smaller differences would be expected from an adult population. Moreover, the sample size was also quite small (27), meaning that only a few “outliers” can make the differences more pronounced than they ought to be.

The researchers noted a possible further explanation for the weaker test-retest reliability. A downward slope of a decreasing gain for every impulse was visually observed within each suppression crHIT assessment as shown in Figure 10. For some participants, it was more pronounced than for others, but they all followed the same pattern. A few studies have noted the decreased mean aVOR gain observed in the SHIMP, but according to our knowledge have not noted a decreasing aVOR gain with every impulse delivered, possibly causing the decreased mean aVOR gain (Rey-Martinez et al., 2018; van Dooren et al., 2022). This decrease in aVOR gain is a phenomenon that requires further investigation. Crane and Demer (1999) investigated VOR cancellation under different circumstances (accelerations and visibility of target). They concluded that the VOR cancellation is possibly triggered by vestibular signals predicting a future head position (Crane & Demer, 1999). Another more likely

conclusion is that the VOR cancellation is triggered by a certain eye displacement (1.5±0.2°) (Crane & Demer, 1999). For all conditions, the VOR cancellation followed a pattern of decreased aVOR gain followed by a corrective saccade as observed by Rey-Martinez et al. (2018). Crane and Demer (1999) also observed the same pattern and corrective saccade. The mechanisms behind the decreasing aVOR gain are still unknown. Rey-Martinez et al. (2018) hypothesize that the VOR inhibition is responsible for the decreased aVOR gain observed for SHIMP. Nevertheless, these arguments could explain why the test-retest reliability is poorer for the suppression crHIT compared to the stationary crHIT.

*The author of this dissertation intends to discuss the suppression results in an article to be submitted for publication in the near future.

5.2 Summary and Discussion of Results

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 (O'Reilly et al., 2010; Rogers, 2010; Gioacchini et al., 2014). 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 anesthesia often required for these scans as well as the financial impact of such expensive scans (Wiener-Vacher, 2008). Such a child must first undergo a full oto-neuro-vestibular clinical examination, an ophthalmologic examination, and an audiovestibular examination, unless neurological symptoms are present (Wiener-Vacher, 2008). It is therefore of utmost importance to have evidence-based vestibular assessment procedures for children, as the crHIT explored in this study.

The crHIT was developed with the intent to overcome some of the limitations observed in the well-known assessment of the vHIT. One of the limitations of the vHIT in smaller children noted by Ross and Helminski (2016) is the lack of inherent neck stiffness making it difficult to elicit impulses greater than 100°/sec^2. 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 (Ross & Helminski, 2016). Weber et al. (2008) found that the ipsilesional gain significantly decreased in vestibular neuritis and unilateral vestibular deafferentation as they increased the accelerations from 750 to 6,000 °/sec^2 resulting in greater asymmetry. 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 (McGarvie et al., 2015). This limitation is overcome by the crHIT as it delivers impulses at 150-160°/sec^2 independent of the inherent neck stiffness of the child and should therefore in theory not fail to capture smaller losses that the vHIT might miss due to the inherent neck stiffness in children.

The measured stationary crHIT gain measurements are well within the normative range for vHIT gain measurements of the aVOR (McGarvie et al., 2015; Ross & Helminski 2016). Rey-Martinez and colleagues (2018) and van Dooren and colleagues (2022) both observed a decreased gain for SHIMP compared to HIT as seen in this study. This study further investigated the reliability of the crHIT in both stationary and suppression conditions by determining the LoA, RC, and error rate. The differences seen for the stationary crHIT for LoA were very small, indicating a good test-retest reliability clinically. For the suppression crHIT the differences seen were larger than for the stationary crHIT, yet still relatively small, indicating clinically that even with the differences present between the measurements the participants still present with results ranging from normative values to a slightly reduced aVOR gain as observed by Rey-Martinez and colleagues (2018) and Van Dooren and colleagues (2022). The error rate shows the average deviations between measurements of the same participant were estimated at 3.7% indicating a low deviation between measurements, hence one can expect a good test-retest reliability. The same was seen for the suppression crHIT. The suppression crHIT error rates are larger indicating weaker

test-retest reliability compared to the stationary crHIT. It is bothering to measure such a difference between the two conditions of stationary and suppression crHIT, as the exact same sample was used for both. It can be hypothesized that the downward-sloping gain observed with each impulse (Figure 7) is responsible for the greater differences measured for the suppression crHIT compared to the stationary crHIT.

The crHIT proved to be child friendly but needs further development to be more appropriate for younger children (< 6 years), as the VOG goggles are too large, and the child's head does not reach the head restraints if they are too short. Other tools, such as eye-tracking cameras or electrodes should also be explored further to measure eye movements in a more child friendly manner, instead of heavy head mounted VOG goggles (Wiener-Vacher & Wiener, 2017; Janky & Patterson, 2020).

5.3 Clinical Implications

The crHIT shows great potential as a supplementary assessment in the pediatric vestibular test battery. Each protocol (stationary and suppression crHIT) only takes between 1-2 minutes to run. During these protocols, 12 exact impulses are delivered to the left and the right measuring the aVOR gain and the presence of saccades. This is a fast testing time. Other vestibular assessments can also be done using the NOCT. This will reduce the overall test time, if the patient is already set up in the chair, as the patient will not need to be reset and additional calibration is not required. The impulses are delivered at predetermined acceleration and velocity rates, thereby overcoming the challenge of having an experienced examiner deliver multiple impulses until valid responses are attained.

The prohibitive pricing and rarity of the equipment pose a challenge for the crHIT. Only a limited number of clinics worldwide own a NOTC. This makes the crHIT unavailable to the greater population. Another downside is that the crHIT currently only assesses

the HSCC and not the vertical canals. Further development is taking place to expand on the crHIT to be able to additionally assess the vertical canals by placing the patient in the correct position to stimulate these canals.

Concluding from the results of this study the stationary crHIT can reliably be utilized for children in a clinical setting. However, further research is required to confirm the sensitivity of crHIT in detecting aVOR abnormalities. The suppression crHIT shows a weaker test-retest reliability, which is possibly due to the prominent downward slope gain decrease detected. Future studies are needed to compare the suppression crHIT reliability to, as this is the first study investigating the repeatability of the suppression crHIT.

5.3 Strengths and Limitations of the Study

Strengths:

- The stationary crHIT gain measurements presented with a good test-retest reliability indicating a good validity of the results reported in the study. Although the suppression crHIT gain measurements only presented with a relatively good test-retest reliability this still indicates good validity for the purposes of this study.
- Furthermore, the gain results obtained in the study reflect those gain results reported in published articles.
- Another strength of this study is its highlighting of areas for future research that could be of value for future clinical practice in pediatric vestibular testing.

Limitations:

- A limitation of the study was the challenge that COVID-19 restrictions placed on the recruiting of children younger than 8 years. As this study focuses on the

pediatric population it would be valuable to include younger participants in future research.

- Although the researchers had enough participants according to the g-power analysis, some of the data had to be omitted due to artifacts. This resulted in a smaller sample of data that the researchers could use.
- Only one study, published by Furman and colleagues in 2017, introduced the idea of the crHIT. Therefore, very limited resources and published research are available to compare the results of this study.
- A further constraint was that the sample selected was limited to middle-class Afrikaans and English-speaking children, due to convenience and the use of snowball sampling. For future research, a sample with greater ethnical diversity, for example including children from rural areas, should be used. These children grow up with different cultural beliefs and under very different circumstances, which makes it difficult to predict their reaction to the testing procedure.

5.4 Recommended Future Research

Investigating the sensitivity of the crHIT in detecting vestibular deficiencies.

The study determined that the crHIT has a good test-retest reliability and is a reliable tool to use in pediatric vestibular assessments; however, no research has been done focusing on the sensitivity and specificity of the crHIT in children with vestibular dysfunctions. This needs to be further investigated to provide practitioners with an assurance that the crHIT will accurately detect dysfunction if present.

Investigating the clinical reliability of the crHIT in children younger than 8 years.

The current study did not include children younger than 8 years. The crHIT shows great potential in assessing HSCC functioning in children younger than 8 years; however, further modifications in terms of the chair, goggles, and head restraint sizes are required. This needs to be investigated in children younger than 8 years.

Investigating the use of tracking cameras and electrodes to measure eye movements during the crHIT for younger children.

Eye-tracking cameras and electrodes are common methods used for recording eye movements in younger children during vestibular testing (Janky & Patterson, 2020; Wiener-Vacher & Wiener, 2017). These methods of recording eye movements show great potential in pediatric crHIT assessment in children that are too small to physically wear VOG goggles or children that do not tolerate wearing VOG goggles for various reasons.

Investigate the downward-sloping gain pattern of the head-fixed target condition of the crHIT.

In this study, researchers visually noted a downward-sloping gain with each impulse administered during the suppression crHIT. Further research is needed to investigate the possible cause and mechanism underlying the decreasing aVOR gain measured.

Investigate the test-retest reliability of the head-fixed target condition for children with a larger sample size.

The study proved a good test-retest reliability for the earth-bound target condition, however for the head-fixed target condition, it was weaker due to some outliers. As the sample size was not very larger it will be worth investigating the test-retest reliability of the head-fixed target condition crHIT with a larger sample size to confirm whether differences are actually as big as observed, or if they were present because of the small sample size.

5.5 Conclusion

In conclusion, the crHIT presents good test-retest reliability for the stationary crHIT. It is child friendly and overcomes some of the challenges observed in the vHIT and could serve as a complimentary assessment for HSCC functioning in children. The suppression crHIT presents with weaker test-retest reliability with an overall decreased gain as observed in other SHIMP studies. In spite of this, the downward slope noted

for the aVOR gain requires further investigation as to its origin and reliability for clinical diagnostic testing in children.

Reference List

Abolpour Moshizi, S., Pastras, C. J., Sharma, R., Parvez Mahmud, M. A., Ryan, R., Razmjou, A., & Asadnia, M. (2022). Recent advancements in bioelectronic devices to interface with the peripheral vestibular system. *Biosensors and Bioelectronics*, 214, 114521. https://doi.org/10.1016/j.bios.2022.114521

Adamović, T., Jurišić-Škevin, A., Madić, D., Sovilj, M., Jeličić, L., Maksimović, S., & Subotić, M. (2020). Head righting reflex in newborns as the predictive factor of early child development: a longitudinal study. *Early Child Development and Care*, *129*(5), 1–13. https://doi.org/10.1080/03004430.2020.1798419

Anderson, D., Nelson, J. & Fowler, S. 1978. Developmental Assessment Schema. In Northcott, W. H. (Ed.). *Curriculum Guide: Hearing Impaired Children (0-3 years) and their Parents*. Washington DC: The Alexander Bell Association for the Deaf, Inc.

Agrup, C., Gleeson, M., & Rudge, P. (2007). The inner ear and the neurologist. *Journal of Neurology, Neurosurgery, and Psychiatry*, *78*(2), 114–122. https://doi.org/10.1136/jnnp.2006.092064

Alhabib, S. F., & Saliba, I. (2016). Video head impulse test: a review of the literature. *European Archives of Oto-Rhino-Laryngology*, *274*(3), 1215–1222. https://doi.org/10.1007/s00405-016-4157-4

Barnhart, H. X., & Barboriak, D. P. (2009). Applications of the Repeatability of Quantitative Imaging Biomarkers: A Review of Statistical Analysis of Repeat Data Sets. *Translational Oncology*, *2*(4), 231–235. https://doi.org/10.1593/tlo.09268

Bland, J. M., & Altman, D. G. (1999). Measuring agreement in method comparison studies. *Statistical Methods in Medical Research*, *8*(2), 135–160. https://doi.org/10.1177/096228029900800204

Bronstein, A. M., Patel, M., & Arshad, Q. (2014). A brief review of the clinical anatomy of the vestibular-ocular connections—how much do we know? *Eye*, *29*(2), 163–170. https://doi.org/10.1038/eye.2014.262

Cohen, H., & Keshner, E. A. (1989). Current Concepts of the Vestibular System Reviewed: 2. Visual/Vestibular Interaction and Spatial Orientation. *American Journal of Occupational Therapy*, *43*(5), 331–338. https://doi.org/10.5014/ajot.43.5.331

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences*. L. Erlbaum Associates.

Crane, B. T., & Demer, J. L. (1999). Latency of voluntary cancellation of the human vestibulo-ocular reflex during transient yaw rotation. *Experimental Brain Research*, *127*(1), 67–74. https://doi.org/10.1007/s002210050774

De Kegel, A., Maes, L., Baetens, T., Dhooge, I., & Van Waelvelde, H. (2012). The influence of a vestibular dysfunction on the motor development of hearing-impaired children. *The Laryngoscope*, *122*(12), 2837–2843. https://doi.org/10.1002/lary.23529

Franco, E. S., & Panhoca, I. (2008). Vestibular function in children underperforming at school. *Brazilian Journal of Otorhinolaryngology*, *74*(6), 815–825. https://doi.org/10.1016/S1808-8694(15)30141-5

Furman, J. M., Kiderman, A. D., & Shirey, I. A. (2020). *APPARATUS AND METHOD FOR COMPUTERIZED ROTATIONAL HEAD IMPULSE TEST* (The United States Patent and Trademark Office Patent).

https://patentimages.storage.googleapis.com/cf/6a/83/334b5ed4f8530e/US10542927.pdf

Furman, J. M., Shirey, I., Roxberg, J., & Kiderman, A. (2016). The horizontal computerized rotational impulse test. *Journal of Vestibular Research*, *26*(5-6), 447–457. https://doi.org/10.3233/ves-160595

Gedik-Soyuyuce, O., Gence-Gumus, Z., Ozdilek, A., Ada, M., & Korkut, N. (2021). Vestibular disorders in children: A retrospective analysis of vestibular function test findings. *International Journal of Pediatric Otorhinolaryngology*, *146*, 110751. https://doi.org/10.1016/j.ijporl.2021.110751

Giavarina, D. (2015). Understanding Bland Altman analysis. *Biochemia Medica*, *25*(2), 141–151. https://doi.org/10.11613/bm.2015.015

Gioacchini, F. M., Alicandri-Ciufelli, M., Kaleci, S., Magliulo, G., & Re, M. (2014). Prevalence and diagnosis of vestibular disorders in children: A review. *International Journal of Pediatric Otorhinolaryngology*, *78*(5), 718–724. https://doi.org/10.1016/j.ijporl.2014.02.009

Gonçalves, D. U., Felipe, L., & Lima, T. M. A. (2008). Interpretation and use of caloric testing. *Brazilian Journal of Otorhinolaryngology*, *74*(3), 440–446. https://doi.org/10.1016/s1808-8694(15)30580-2

Halmagyi, G. M., Chen, L., MacDougall, H. G., Weber, K. P., McGarvie, L. A., & Curthoys, I. S. (2017). The Video Head Impulse Test. *Frontiers in Neurology*, *8*. https://doi.org/10.3389/fneur.2017.00258

Inoue, A., Iwasaki, S., Ushio, M., Chihara, Y., Fujimoto, C., Egami, N., & Yamasoba, T. (2013). Effect of Vestibular Dysfunction on the Development of Gross Motor Function in Children with Profound Hearing Loss. *Audiology and Neurotology*, *18*(3), 143–151. https://doi.org/10.1159/000346344

J. Martin Bland, & Altman, DouglasG. (1986). STATISTICAL METHODS FOR ASSESSING AGREEMENT BETWEEN TWO METHODS OF CLINICAL MEASUREMENT. *The Lancet*, *327*(8476), 307–310. https://doi.org/10.1016/s0140-6736(86)90837-8

Jahn, K., Langhagen, T., Schroeder, A. S., & Heinen, F. (2011). Vertigo and Dizziness in Childhood − Update on Diagnosis and Treatment. *Neuropediatrics*, *42*(04), 129–134. https://doi.org/10.1055/s-0031-1283158

Janky, K. L., & Patterson, J. (2020). The Relationship Between Rotary Chair and Video Head Impulse Testing in Children and Young Adults With Cochlear Implants. *American Journal of Audiology (Online)*, *29*(4), 898–906. https://doi.org/10.m44/2020_AJA-20-00079

Khater, A. M., & Afifi, P. O. (2016). Video head-impulse test (vHIT) in dizzy children with normal caloric responses. *International Journal of Pediatric Otorhinolaryngology*, *87*, 172–177. https://doi.org/10.1016/j.ijporl.2016.06.030

Lee, J. D., Kim, C., Hong, S. M., Kim, S. H., Suh, M., Kim, M., Shim, D. B., Chu, H., Lee, N. H., Kim, M., Hong, S. K., & Seo, J. (2017). Prevalence of vestibular and balance disorders in children and adolescents according to age: A multi-center study. *International Journal of Pediatric Otorhinolaryngology*, *94*, 36–39. https://doi.org/10.1016/j.ijporl.2017.01.012

MacDougall, H. G., McGarvie, L. A., Halmagyi, G. M., Curthoys, I. S., & Weber, K. P. (2013). The Video Head Impulse Test (vHIT) Detects Vertical Semicircular Canal Dysfunction. *PLoS ONE*, *8*(4), e61488. https://doi.org/10.1371/journal.pone.0061488

MacDougall, H. G., McGarvie, L. A., Halmagyi, G. M., Rogers, S. J., Manzari, L., Burgess, A. M., Curthoys, I. S., & Weber, K. P. (2016). A new saccadic

indicator of peripheral vestibular function based on the video head impulse test. *Neurology*, *87*(4), 410–418. https://doi.org/10.1212/wnl.0000000000002827

MacDougall, H. G., Weber, K. P., McGarvie, L. A., Halmagyi, G. M., & Curthoys, I. S. (2009). The video head impulse test: Diagnostic accuracy in peripheral vestibulopathy. *Neurology*, *73*(14), 1134–1141. https://doi.org/10.1212/WNL.0b013e3181bacf85

Mantokoudis, G., Saber Tehrani, A. S., Kattah, J. C., Eibenberger, K., Guede, C. I., Zee, D. S., & Newman-Toker, D. E. (2014). Quantifying the Vestibulo-Ocular Reflex with Video-Oculography: Nature and Frequency of Artifacts. *Audiology and Neurotology*, *20*(1), 39–50. https://doi.org/10.1159/000362780

McGarvie, L. A., MacDougall, H. G., Halmagyi, G. M., Burgess, A. M., Weber, K. P., & Curthoys, I. S. (2015). The Video Head Impulse Test (vHIT) of Semicircular Canal Function – Age-Dependent Normative Values of VOR Gain in Healthy Subjects. *Frontiers in Neurology*, *6*(154). https://doi.org/10.3389/fneur.2015.00154

Mourad Abd El-Mawgoud, S. (2020). Personal audio devices and the risk of hearing loss in young adults. *Electronic Physician*, *12*(1), 7662–7667. https://doi.org/10.19082/7662

Nguyen, J., Berger, J., Curthoys, I., Held, V., Zaubitzer, L., Hülse, R., Rotter, N., & Schell, A. (2021). Vestibular testing in children – The suppression head impulse (SHIMP) test. *International Journal of Pediatric Otorhinolaryngology*, 110921. https://doi.org/10.1016/j.ijporl.2021.110921

O'Reilly, R. C., Morlet, T., Nicholas, B. D., Josephson, G., Horlbeck, D., Lundy, L., & Mercado, A. (2010). Prevalence of Vestibular and Balance Disorders in

Children. *Otology & Neurotology*, *31*(9), 1. https://doi.org/10.1097/mao.0b013e3181f20673

Perez-Fernandez, N., & Eza-Nuñez, P. (2015). Normal Gain of VOR with Refixation Saccades in Patients with Unilateral Vestibulopathy. *The Journal of International Advanced Otology*, *11*(2), 133–137. https://doi.org/10.5152/iao.2015.1087

Rey-Martinez, J., Thomas-Arrizabalaga, I., Espinosa-Sanchez, J. M., Batuecas-Caletrio, A., Trinidad-Ruiz, G., Matiño-Soler, E., & Perez-Fernandez, N. (2018). Vestibulo-ocular reflex gain values in the suppression head impulse test of healthy subjects. *The Laryngoscope*, *128*(10), 2383–2389. https://doi.org/10.1002/lary.27107

Robinson, D. A. (1963). A Method of Measuring Eye Movemnent Using a Scieral Search Coil in a Magnetic Field. *IEEE Transactions on Bio-Medical Electronics*, *10*(4), 137–145. https://doi.org/10.1109/TBMEL.1963.4322822

Rodriguez, A., & Janky, K. (2018). Quantitative Vestibular Function Testing in the Pediatric Population. *Seminars in Hearing*, *39*(03), 257–274. https://doi.org/10.1055/s-0038-1666817

Rogers, C. (2010). A review of childhood vestibular disorders. *South African Family Practice*, *52*(6), 514–517. https://doi.org/10.1080/20786204.2010.10874036

Ross, L. M., & Helminski, J. O. (2016). Test-retest and Interrater Reliability of the Video Head Impulse Test in the Pediatric Population. *Otology & Neurotology*, *37*(5), 558–563. https://doi.org/10.1097/mao.0000000000001040

Roy, F. D., & Tomlinson, R. D. (2009). Characterization of the Vestibulo-Ocular Reflex Evoked by High-Velocity Movements. *The Laryngoscope*, *114*(7), 1190–1193. https://doi.org/10.1097/00005537-200407000-00011

Sullivan, L. M. (2008). Repeated Measures. *Circulation*, *117*(9), 1238–1243. https://doi.org/10.1161/circulationaha.107.654350

van Dooren, T., Starkov, D., Lucieer, F., Dobbels, B., Janssen, M., Guinand, N., Pérez Fornos, A., Kingma, H., Van Rompaey, V., & van de Berg, R. (2022). Suppression Head Impulse Test (SHIMP) versus Head Impulse Test (HIMP) When Diagnosing Bilateral Vestibulopathy. *Journal of Clinical Medicine*, *11*(9), 2444. https://doi.org/10.3390/jcm11092444

Weber, K. P., Aw, S. T., Todd, M. J., McGarvie, L. A., Curthoys, I. S., & Halmagyi, G. M. (2008). Head impulse test in unilateral vestibular loss: Vestibulo-ocular reflex and catch-up saccades. *Neurology*, *70*(6), 454–463. https://doi.org/10.1212/01.wnl.0000299117.48935.2e

Wiener-Vacher, S. R. (2008). Vestibular disorders in children. *International Journal of Audiology*, *47*(9), 578–583. https://doi.org/10.1080/14992020802334358

Wiener-Vacher, S. R., Hamilton, D. A., & Wiener, S. I. (2013). Vestibular activity and cognitive development in children: perspectives. *Frontiers in Integrative Neuroscience*, *7*. https://doi.org/10.3389/fnint.2013.00092

Wiener-Vacher, S. R., & Wiener, S. I. (2017). Video Head Impulse Tests with a Remote Camera System: Normative Values of Semicircular Canal Vestibulo-Ocular Reflex Gain in Infants and Children. *Frontiers in Neurology*, *8*. https://doi.org/10.3389/fneur.2017.00434

Yacovino, D. A., Martin, L. A., Perez Akly, M., & Hain, T. C. (2018). Characteristics of vestibular corrective saccades in patients with slow visual saccades, vestibular disorders and controls: A descriptive analysis. *PLOS ONE*, *13*(5), e0197079. https://doi.org/10.1371/journal.pone.0197079

Yap, B. W., & Sim, C. H. (2011). Comparisons of various types of normality tests. *Journal of Statistical Computation and Simulation*, *81*(12), 2141–2155. https://doi.org/10.1080/00949655.2010.520163

Yip, C. W., Glaser, M., Frenzel, C., Bayer, O., & Strupp, M. (2016). Comparison of the Bedside Head-Impulse Test with the Video Head-Impulse Test in a Clinical Practice Setting: A Prospective Study of 500 Outpatients. *Frontiers in Neurology*, *7*. https://doi.org/10.3389/fneur.2016.00058

Appendices

Appendix A: Ethical Clearance Letter

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

Faculty of Humanities
Fakulteit Geesteswetenskappe
Lefapha la Bomotho

Humanities 100. Since 1919

4 March 2021

Dear Miss N Mittendorf

Project Title:	Test-retest reliability of the computerized rotational head impulse test in the paediatric population
Researcher:	Miss N Mittendorf
Supervisor(s):	Dr BM Heinze
Department:	Speech Language Path and Aud
Reference number:	17001529 (HUM022/1220)
Degree:	Masters

I have pleasure in informing you that the above application was **approved** by the Research Ethics Committee on 25 February 2021. Data collection may therefore commence.

Please note that this approval is based on the assumption that the research will be carried out along the lines laid out in the proposal. Should the actual research depart significantly from the proposed research, it will be necessary to apply for a new research approval and ethical clearance.

We wish you success with the project.

Sincerely,

Prof Innocent Pikirayi
Deputy Dean: Postgraduate Studies and Research Ethics
Faculty of Humanities
UNIVERSITY OF PRETORIA
e-mail: PGHumanities@up.ac.za

Appendix B: Informed Consent Form

UNIVERSITEIT VAN PRETORIA
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Faculty of Humanities
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Humanities 100. Since 1919

Department of Speech-Language Pathology and Audiology

PARENTAL OR LEGAL GUARDIAN INFORMATION LETTER & INFORMED CONSENT

STUDY TITLE:

Test-retest Reliability of the Computerized Head Impulse Test in the Paediatric Population

Principal Investigator: **Nicole Mittendorf**
Supervisor: **Dr Barbara Heinze**

Institution: University of Pretoria

Should you have any questions or concerns at any point during the study, please feel free to contact us.

Researcher: Nicole Mittendorf
Phone: 0763472263
Email: nicole.mittendorf@gmail.com

Supervisor: Dr B. Heinze
Phone: 0834232925
Email: barbara.heinze@up.ac.za

DATE AND TIME OF FIRST INFORMED CONSENT DISCUSSION:

			:
date	**month**	**year**	**Time**

Dear Mr. /Mrs. _____

We invite your child to participate in a research study. This information document will help you to decide if your child may want to participate. Before you agree that your child may take part, you should fully understand what it will entail and what is expected of your child.

BACKGROUND OF THIS STUDY

Childhood vestibular disorders can have detrimental effects on intellectual and physical development, as they can cause learning difficulties, delays in gross motor skills and spatial problems (Gioacchini et al., 2014; Rogers, 2010). It is therefore essential that children are identified and tested as soon as possible to guide health care professionals in appropriate

treatment. For this study we are looking at a specific test called the computerized head impulse test (crHIT), which tests the function of the semi-circular canals of the vestibular organ responsible for keeping a steady gaze during head movements. The crHIT eliminates multiple disadvantages present during other tests that also assess the semi-circular canals of the vestibular organ. The crHIT shows great potential for paediatric assessments in quantifying the vestibular loss of each semi-circular canal individually. However, no research has been done to establish the clinical validity of the crHIT in the paediatric population and, therefore this study will focus on establishing the test-retest reliability of the crHIT in typically developing children to determine the usefulness of the crHIT as a clinical tool.

THE NATURE AND PURPOSE OF THIS STUDY

The study aims to determine the test-retest reliability of the computerized rotational head impulse test in typically developing children and adolescents.

EXPLANATION OF PROCEDURES AND WHAT WILL BE EXPEXTED FROM PARTICIPANTS

The questionnaire and all the tests will be done at the Department of Speech-Language Pathology and Audiology at the University of Pretoria.

Step 1:

We will begin by ask you as a parent to fill in a questionnaire, which will enquire about your child's development and medical history relevant to this study. It is important that we only test healthy, typically developing children for this study and therefore we need you to be very honest with us about all the information asked on the questionnaire.

Step 2:

To screen if your child has normal horizontal semi-circular functioning, we will do a test called: Video Head-Impulse Test.
For this test your child will be sitting on a chair and we will strap goggles on their head. We will then induce very small, fast head impulses randomly to the right and left side. A camera attached to the goggles will record their eye movement. All your child needs to do is keep looking at a dot on the wall in front of them. A camera attached to the goggles will record their eye movement.

Photo illustrating the setup for the testing procedure.

Step 3:

To collect the data, which we need for this study, we will do the next test called: Computerized Head-Impulse Test.
For this test, your child will be seated and securely strapped on a rotary chair in a dark light proof booth. We will also place head fastenings on their head to keep your child's head very still during the testing procedure. You are allowed to be inside this dark booth with your child the entire time.
We will place goggles and headphones on their head. The goggles also have a camera attached which allows us to record their eye movement and we will use the headphones to talk to your child during the testing procedure, specifically to remind them of instructions and reassure them.
Your child will have a microphone as well through which they can talk to us the entire time while we are testing.

Once everything is set up your child will be asked to keep their gaze on a target (red laser dot) in front of them:

- For the one version of the test the target will stay at the front.
- For the second version of the test the target will move with the chair.

We will tell your child which of the above-mentioned targets will be used before the test begins. Once the test begins, the rotary chair will randomly turn quickly to the right or the left side for 12 consecutive turns, during which it is important that your child keeps their eyes on the target the entire time. Both versions of the test will be done once for each testing session.
In total we will do three testing sessions. The second session will take place 1-6 hours after the first session and the third session will take place 24 hours to two weeks thereafter. We will inform you of the exact times.

POSSIBLE RISK AND DISCOMFORT INVOLVED
The tests will not hurt your child at all. However, they might experience some discomfort from the goggles on their face as well as the head fastenings which keep their head still for the testing procedure. Each testing session will take about 30 minutes (the test only takes a few seconds but the set up takes a little longer); however this is dependent on your child's cooperation.

POSSIBLE BENEFITS OF THIS STUDY
Although your child will not benefit directly from the study, the results of the study will be contributing to necessary research. Your child will obtain their results from the tests which will inform them of their current vestibular functioning, specifically the horizontal semi-circular canals of their vestibular sensory organ.

YOUR CHILD'S RIGHTS AS A PARTICIPANT
Your child's participation in this study is entirely voluntary. Your child can refuse to participate or stop at any time during the study without giving any reason without any negative consequences.

ETHICS APPROVAL
This Protocol was submitted to the Faculty of Humanity Research Ethics Committee at the University of Pretoria and written approval has been granted by that committee. The study has been designed in agreement with the Declaration of Helsinki (last update: October 2013), which describes recommendations guiding doctors in biomedical research involving humans. A copy of the Declaration may be attained from the investigator should you wish to review it.

INFORMATION AND CONTACT PERSON
The contact persons for the study are me, Nicole Mittendorf (Researcher) and Dr Barbara Heinze (Supervisor). As mentioned above if you or your child have any questions about the study please contact me at any time, or alternatively you may contact my supervisor. **Refer to contact details mentioned at the beginning of the letter.**

COMPENSATION
Your child will not be paid to take part in the study.

CONFIDENTIALITY

All information about your child will be kept strictly confidential. Once we have analysed the information no one will be able to identify your child. Research reports and articles in scientific journals will not include any information that may identify your child.

CONSENT TO PARTICIPATE IN THIS STUDY

- I confirm that the person requesting my consent for my child to take part in this study has told me about the nature and process, any risks or discomforts, and the benefits of the study.
- I have also received, read and understood the above written information about the study.
- I have had adequate time to ask questions and I have no objections for my child to participate in this study.
- I am aware that the information obtained in the study, including personal details, will be anonymously processed and presented in the reporting of results.
- I understand that my child will not be penalised in any way should my child wish to discontinue with the study and that withdrawal will not have any negative consequences for my child.
- My child is participating willingly.
- I agree that all data and results obtained for this study may be used in future studies at the University of Pretoria given that my child's identity remains confidential.
- I have received a signed copy of this informed consent agreement.

If you have read the above and have no further questions, please sign below to give consent that your child (name of child) _____ may participate in the above-described study.

_____	_____
Parent/Guardian of participant Name	**Researcher Name**
_____	_____
Parent/Guardian of participant signature	**Researcher Signature**
_____	_____
Date	**Date**

Appendix C: Child Assent Form (English)

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Lefapha la Bomotho

Humanities 100. Since 1919

Department of Speech-Language Pathology and Audiology

CHILD INFORMATION AND ASSENT LETTER

I am Nicole Mittendorf from the University of Pretoria. I am doing a study to find out if this test correctly tests the part of your ear that helps you balance. We are asking you to take part in the research study because we need your good ears to help us do this study.

What will happened and what will you need to do?

For this study there will be two parts. I will explain them both to you and you can ask me any questions that you have at any time.

Part 1:

For the first part all you have to do is sit on a chair and relax. I will put goggles on your head that have a camera on them, which will make a video your eyes when they move really fast. For this part I will stand behind you and hold your head. You will see a dot on the wall infront of you which you have to look at while keeping your eyes wide open. Then I will move your head very little but very fast to the right side and the left side. I will do that a few times. It is important that you just relax the whole time and keep your neck lose so I can easily move your head.

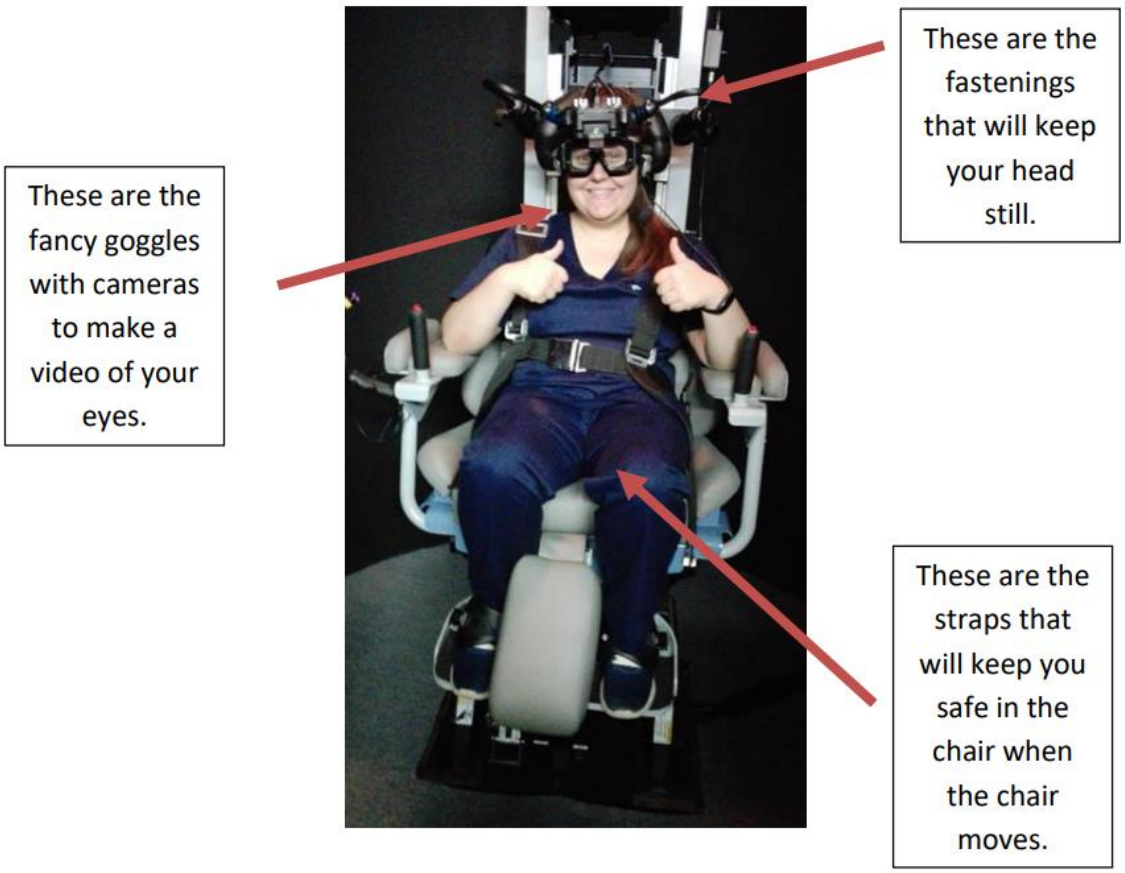
I do this test to make sure that your ears and your balance works well before we carry on with part two.

We will do part one only once.

Room 3-11, Communication Pathology Building
University of Pretoria, Private Bag X20
Hatfield 0028, South Africa
Tel +27 (0)12 420 5358 | Fax +27 (0)12 420 3517
Email Barbara.heinze@up.ac.za | www.up.ac.za

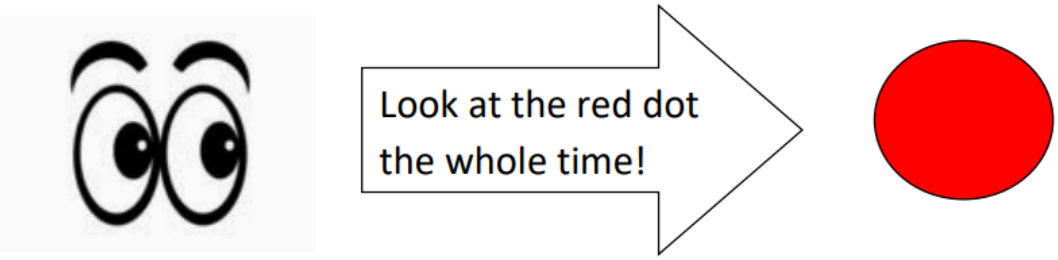
Part 2:

1. You will sit in a chair and we will use straps, like a seatbelt, to make sure you are safe when the chair moves. We will also use fastenings to keep your head still and put goggles on your head.
2. You will be inside a very dark room that looks like a spaceship. Someone can stay inside the spaceship with you if you want.



3. When you are ready the chair will quickly turn to the right or the left and then quickly stop. While the chair turns you have to keep looking at the dot in front of you. Sometimes the dot will also move with the chair and sometimes it will stay still.
4. We will part two three times. Two of the times will be on the same day and then the third time will be within the next two weeks afterwards.

5. For every test session we will do two short tests like I explained in the begining, where the chair will turn to the right or the left and all you need to do is keep looking at the dot. We will tell you when the test will have the moving dot or the dot that stays still.



We will keep all your answers, and will not show them to anyone. Only people from the University of Pretoria working on the study will see them.
Nothing dangerous will happen to you while you are taking part in this study.
You can feel good about helping us to find out if this test works well, so we can use it to help other children who have problems with their ears and balance.

You should know that:

- You do not have to be in this study if you do not want to. You won't get into any trouble with the University, me or your parents if you say no.
- You may stop being in the study at any time.
- Your parent(s)/guardian(s) were asked if it is OK for you to be in this study. Even if they say it's OK, it is still your choice if you want to be a part of this study or not.
- You can ask any questions you have, now or later. If you think of a question later, you or your parents can contact me or my supervisor.

Me – Nicole Mittendorf
Phone: 0763472263
Email: nicole.mittendorf@gmail.com

My Supervisor – Dr Heinze
Phone: 0834232925
Email: barbara.heinze@up.ac.za

1. Do you understood what you will be doing for this study?	YES 		NO 	
2. Have all your questions been answered?	YES 		NO 	
3. Have you talked to your parent(s)/legal guardian about this project?	YES 		NO 	
4. Do you agree to take part in this research?	YES 		NO 	

If you want to help me and you said yes to all the questions write your name or draw a picture of yourself.

_____	_____
Witness Name	Researcher Name
_____	_____
Witness Signature	Researcher Signature
_____	_____
Date	Date

Appendix D: Child Assent Form (Afrikaans)

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Department of Speech-Language Pathology and Audiology

KINDERINLIGTING EN INSTEMMINGSBRIEF

Ek is Nicole Mittendorf van die Universiteit van Pretoria. Ek doen 'n studie om vas te stel of ‘n toets die regte resultate gee. Die toets waarna ons gaan kyk toets die deel van jou oor wat jou help om te balanseer. Ons vra jou om deel te neem aan die navorsing omdat ons jou goeie ore nodig het om ons te help om hierdie studie suksesvol te doen.

Wat sal gebeur en wat sal jy moet doen?

Vir hierdie studie sal daar twee dele wees. Ek sal hulle albei aan jou verduidelik, en jy kan my enige tyd enige vrae vra.

Deel 1:

Vir die eerste deel hoef jy net op 'n stoel te sit en te ontspan. Jy sal ‘n bril dra met ‘n kamera in, wat 'n video van jou oë sal neem wanneer dit vinnig beweeg. Vir hierdie deel sal ek agter jou staan en jou kop vashou. Voor jou op die muur sal daar ‘n punt wees waarna jy moet kyk terwyl jy jou oë wyd oophou. Ek sal jou kop baie min, maar vinnig na die regter- en linkerkant beweeg. Ek sal dit 'n paar keer doen. Dit is belangrik dat jy net die hele tyd ontspan en jou nek ontspanne hou, sodat ek jou kop maklik kan beweeg.

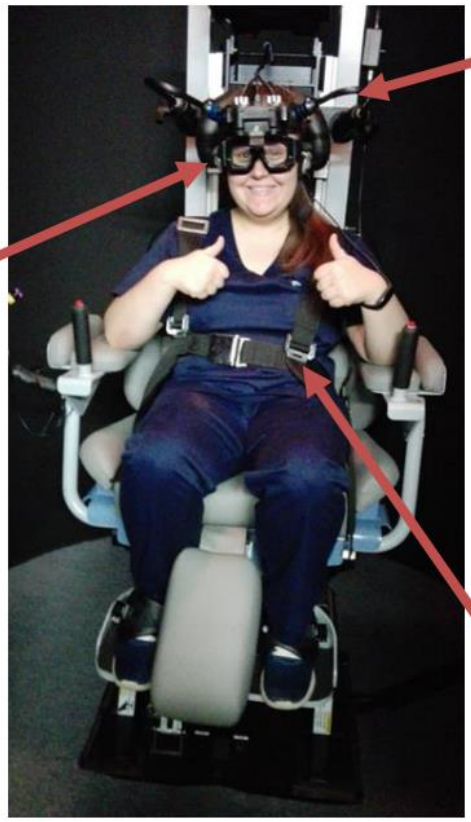
Ek doen hierdie toets om seker te maak dat jou ore en jou balans goed werk voordat ons met deel twee voortgaan.

Jy hoef deel 1 net eenkeer te doen en dit sal net n paar minute neem.

Room 3-11, Communication Pathology Building
University of Pretoria, Private Bag X20
Hatfield 0028, South Africa
Tel +27 (0)12 420 5358 | Fax +27 (0)12 420 3517
Email Barbara.heinze@up.ac.za | www.up.ac.za

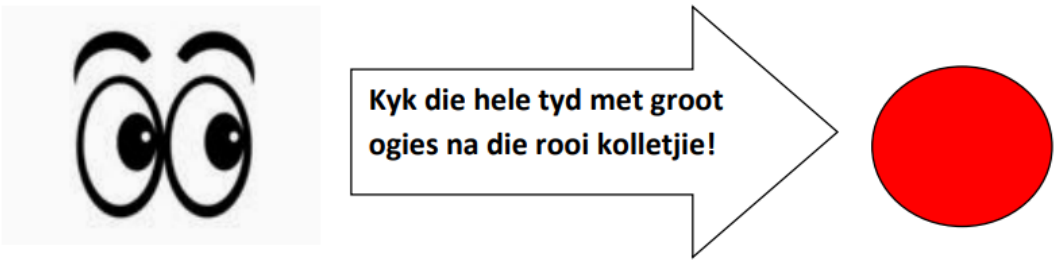
Deel 2:

1. Jy sal op 'n stoel sit en ons sal ‘n harnas, soos 'n veiligheidsgordel, gebruik om seker te maak dat jy veilig en vas is wanneer die stoel beweeg. Ons sal ook 'n kopstut gebruik om jou kop stil te hou en jy sal weer ‘n bril dra met ‘n kamera in.
2. Jy sal in 'n baie donker kamer wees wat soos 'n ruimteskip lyk. As jy wil kan iemand die hele tyd saam met jou daar binne bly.



3. Wanneer jy gereed is, sal die stoel vinnig na regs of links draai en dan vinnig stop. Terwyl die stoel draai, moet jy aanhou kyk na die kolletjie voor jou. Soms sal die kolletjie ook met die stoel beweeg en soms bly hy stil.
4. Deel twee sal ons drie keer doen. Ons sal die deel twee keer op een dag doen en die derde keer binne die volgende twee weke daarna.

5. Vir elke sessie sal ons twee kort toetse doen soos ek aan die begin verduidelik het. Die stoel sal na regs of links draai en al wat jy hoef te doen is om na die kol te kyk. Ons sal vir jou sê wanneer die toets die bewegende kolletjie het of die kolletjie wat stil staan.



Ons sal al jou antwoorde hou en dit vir niemand wys nie. Slegs mense van die Universiteit van Pretoria, wat aan die studie werk, sal dit sien.

Jy sal teen alle tye veilig wees en niks van die toetse is gevaarlik nie.

Jy kan trots wees op jouself dat jy ons help om uit te vind of hierdie toets goed werk. Jy is deel van 'n studie om ons te help sodat ons kinders kan help wat balans en oor probleme het.

<u>Jy moet weet dat:</u>

- Jy hoef nie aan hierdie studie deel te neem as jy nie wil nie. Die Universiteit of jou ouers sal nie kwaad wees as jy nee sê nie.
- Jy mag enige tyd ophou om deel te neem aan die studie.
- Jou ouer(s) /voog(de) is gevra of dit reg is dat jy aan hierdie studie deelneem. Selfs al sê hulle dat dit OK is, is dit steeds jou keuse of jy deel wil wees van hierdie studie of nie.
- Jy kan enige vrae wat jy het, nou of later vra. As jy later aan 'n vraag dink, kan jy, of jou ouers, my of my studieleier kontak.

Ek – Nicole Mittendorf
Tel: 0763472263
Epos: nicole.mittendorf@gmail.com

Studieleier – Dr Barbara Heinze
Tel: 0834232925
Epos: barbara.heinze@up.ac.za

1. Verstaan jy wat jy vir hierdie studie gaan doen?	YES 		NO 	
2. Is al jou vrae wat jy het beantwoord?	YES 		NO 	
3. Het jy met jou ouers/ voogde gepraat oor die studie?	YES 		NO 	
4. Stem jy saam om deel te wees van die studie?	YES 		NO 	

As jy my wil help en jy het ja gesê op al die vrae, skryf jou naam of teken 'n prentjie van jouself.

Getuie Naam	Navorser Naam
Getuie Handtekening	Navorser Handtekening
Datum	Datum

Appendix E: Participant Information Form

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

Faculty of Humanities
Fakulteit Geesteswetenskappe
Lefapha la Bomotho

Department of Speech-Language Pathology and Audiology

Participant Information Form

Researcher name:
Screening date:

Participant information

Name & surname:
Birth date:
Age:
Gender: **male** ☐ **female** ☐
Contact number:
Assigned code:

Medical History

1. **Has your child ever had severe trauma or surgery to the ear, head, neck?**
   Yes ☐ **No** ☐
   If yes, please specify
   _____

2. **Does your child have any balance difficulties?**
   Yes ☐ **No** ☐
   If yes, please specify
   _____

3. **Does your child complain of being/feeling dizzy?**
   Yes ☐ **No** ☐
   If yes, please specify
   _____

4. **Has your child been diagnosed with a hearing loss?**
   Yes ☐ **No** ☐
   If yes, please specify
   _____

At what age did your child achieve the following?

Gross Motor Skills	Age (in months)
Sits up with only little support	
Pulls self to stand	
Crawls	
Stands alone temporarily without support	
Walks well alone	
Seats self on chair	
Goes up and down stairs alone, two feet per step	
Kicks large ball	
Balance on one foot	

Is there anything else you would like to bring to our attention that you might feel we need to know?

_____

_____

_____

Appendix F: Data Collection Sheet – crHIT

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

Faculty of Humanities
Fakulteit Geesteswetenskappe
Lefapha la Bomotho

Department of Speech-Language Pathology and Audiology

Data Collection Sheet: crHIT

Researcher:

Test session: 1 ☐ 2 ☐ 3 ☐

Date:		
Time:	**Start**	**End**

Participant information

Participant code:

Participant age:

Participant gender: male ☐ female ☐

Computerized Head Impulse Test					
	Gain (right)	**Gain (left)**	**Asymmetry (%)**	**Score (right)**	**Score (left)**
PROTOCOL 1					
PROTOCOL 2					

Additional Notes:

_____

_____

_____

Appendix G: Written Consent for the use of Figure 1

To whom it may concern

I, Barbara Heinze, give consent that the bellow photo of my daughter, Jenna Heinze, may be used in the dissertation: "Test-retest reliability of the computerized rotational head impulse test in the paediatric population", written by Nicole Mittendorf (principal researcher) for educational purposes.

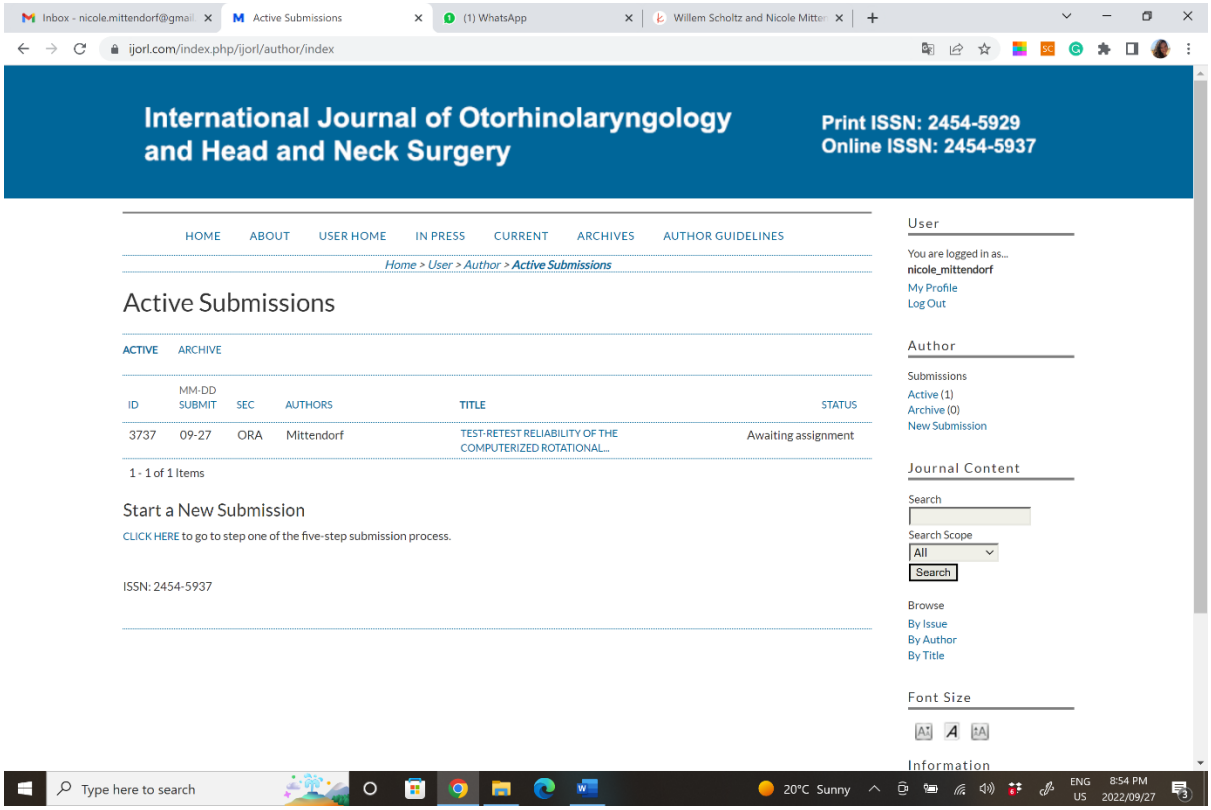
Barbara Heinze

BHeinze

_____

Signature

Appendix H: Proof of Journal Submission


Inbox - nicole.mittendorf@gmail
Active Submissions
(1) WhatsApp
Willem Scholtz and Nicole Mitter
ijorl.com/index.php/ijorl/author/index
International Journal of Otorhinolaryngology and Head and Neck Surgery
Print ISSN: 2454-5929
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3737 09-27 ORA Mittendorf TEST-RETEST RELIABILITY OF THE COMPUTERIZED ROTATIONAL... Awaiting assignment
1 - 1 of 1 Items
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CLICK HERE to go to step one of the five-step submission process.
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