Office of Evidence Based Practice (EBP) – Critically Appraised Topic: Vestibular Disorders Testing

Specific Care Question

In the child <18 years of age, are there tests/assessments to differentiate peripheral vestibular disorders from central vestibular disorders?

Recommendations from the Team

No recommendation can be made on tests to differentiate peripheral vestibular disorders from central vestibular disorders from the included literature. However, this review shows the variability in the studies published on testing for vestibular disorders. Current literature for testing children with cortical or central issues is limited. A gold standard to test or diagnose this debilitating condition is needed. Research is required to establish standard testing and to permit the development of intervention guidelines. When there is a lack of scientific evidence, standard work should be developed, implemented, and monitored.

Literature Summary

Background. The vestibular system includes parts of the inner ear and brain that process sensory inputs and regulate balance (Li, Hoffman, Ward, Cohen, & Rine, 2016). Symptoms of vestibular disorders are vertigo, light-headedness, dizziness, unsteadiness when standing or walking, poor balance, or clumsiness (Gioacchini, Alicandri-Ciufelli, Kaleci, Magliulo, & Re, 2014; Li et al., 2016).From a four-year retrospective review, O'Reilly et al. (2010) reported 2,546 patients who presented to a pediatric health system in the US with dizziness. Unspecified dizziness was diagnosed in approximately 90% of these patients, while peripheral and central vestibular disorder was diagnosed in 6.2%, and 4.1%, respectively. While from the 2012 National Health Interview Survey, Child Balance Survey of parents reporting on their children aged 3-17 years old, the prevalence of vestibular disorders in the United States was 5.3% and prevalence increased as children aged (Li et al., 2016). The prevalence in older children (15-17 years) was 7.5%, while for children 3-5 years the prevalence was 4.1%. Hearing loss diagnoses, such as central hearing loss, sensorineural hearing loss, neural hearing loss are associated with vestibular disorders (O'Reilly et al., 2010).

Common causes of vestibular disorder:

Central Vestibular Disorders	Peripheral Vestibular Disorders
Migarine-associated dizziness (vestibular migraine)	Meniers's syndrome
Vertebrobasiliar ischemic stroke	Benign paroxysmal positional vertigo (BPPV)
Vertebrobasilar insufficiency	Vestibular Neuronitis
	Labyrinthitis
	Vestibular schwannoma
	Perilymphatic fistula
	Superior semicircular canal dehiscence syndrome
	Trauma
	Vestibular hypofunction

Note: Thompson and Amedee (2009)

The number of undiagnosed cases hypothesizes that accurate tests that are both reliable and valid are needed (O'Reilly et al., 2010). Christy, Payne, Azuero, and Formby (2014) sounded the need for valid and reliable testing tools for the assessment of children for vestibular dysfunction. Studies have been published on tests to assess various methods of assessment (see the area within this document entitled *Studies Not Included in this Review, with Exclusion Rationale*), but do not report on sensitivity, specificity, reliability, validity, responsiveness, or usability. Five studies were identified that did report on diagnostic test accuracy (Brodsky, Cusick, Kenna, & Zhou, 2016; Christy et al., 2014; Dannenbaum et al., 2016; Hamilton, Zhou, and Brodsky, 2015; Oyewumi et al., 2016). The small number of studies that report on these items does not permit pooling of data. This review will summarize current literature on the topic.

Study characteristics. The search for suitable studies was completed on January 29, 2019. Andrea Thorne, DPT, MSPT and Brooke Boehmer, DPT

reviewed the 49 titles and/or abstracts found in the search or ancestry search and identified[a] 20 single studies believed to answer the question. After an in-depth review of the remaining articles[b], five answered the questions (see Figure 1).

Diagnostic Test Accuracy. Brodsky et al. (2016) tested the index test, Subjective Visual Vertical testing, against a gold standard of either Rotary Chair test, or bi-thermic water caloric testing, see Table 1. Pediatric subjects with sensioneural hearing loss and typically developed children (control), were tested with index tests of Dynamic Visual Acuity, Head Thrust Test, Modified Clinical Test of Sensory Interaction on Balance, Modified Emory Clinical Chari Test, or the Sensory Organization Test versus a gold standard of cervical VEMP (Christy et al., 2014). Hamilton et al. (2015) completed a study of diagnostic test accuracy in 33 children, 3-19 years of age comparing the results of the index test, Video Head Impulse Test (VHIT), to a gold standard test, Rotary Chair test. While (Oyewumi et al., 2016) reported on the DTA of the Bruininks Oseretsky Test of Motor Proficiency II (BOT-2). See the Appendix for explanations of statistical tests employed when doing research of diagnostic test accuracy.

Reliability and Validity. Christy et al. (2014) reported upon test-retest reliability of multiple tests, while (Dannenbaum et al., 2016) reported on test-retest reliability in subjects with global developmental delay.

Summary

Diagnostic Accuracy.

Gold Standards. The American Academy of Neurology provides gold standard tests for two types of vestibular disorders. Caloric testing is the gold standard for detecting unilateral disorders while the rotational chair test using computer driven chair rotation is the gold standard for bilateral vestibular loss (Fife et al., 2000). The term vestibular loss is used interchangeably with the term vestibular hypofunction (Brodsky et al., 2016).

Subjective Visual Vertical (***SVV).*** The SVV is used to assess peripheral vestibular disorders (Christy et al., 2014). There are three methods to perform this test. They are (a) the hemispheric dome method, (b) the Bucket method, and (c) the light bar. Brodsky et al. (2016) used the laser line (light bar) Micromedical System 2000 (Micromedical Technologies, Chatham, IL). Where a line was projected onto a wall and the patient is instructed to move the line to a vertical position. Christy et al. (2014) employed the Bucket method, where a bucket with a vertical line on the bottom is placed in front of the patient's face, and the patient is instructed to move the line to a vertical position. There was no report using the hemispheric dome method.

Two studies measured the diagnostic accuracy of the SVV to assess vestibular disorders (Brodsky et al., 2016; Christy et al). In Brodsky et al. (2016) there were four groups including peripheral vestibular loss (PVL), benign paroxysmal position vertigo (BPPV), central vertigo (CV), non-vestibular dizziness, and a group of typically developing children as a control group (n = 33). Scores on the SVV were reported by diagnosis group. The mean SVV score was significantly higher in the PVL group as compared to all other groups by one-way ANOVA (p = .002). An SVV score >2° showed a sensitivity of 100% and a specificity of 75% in subjects with PVL (n = 4). However, the variation in the SVV test scores was wide. The researchers recommend using the best three of five trials to calculate mean score.

Study	Test	Comparison
Brodsky et al., (2016)	SVV – Micromedical 2000	SVV was significantly higher in the PVL versus BPPV, NVD and control by one-way ANOVA, p = .002. Comparing the SVV in the PVL group versus all other groups the SVV was higher by multiple comparison, p < .05. In the non-PVL groups there was no in difference in SVV scores If the SVV score ≥ 2 degrees a sensitivity of 100%, specificity 75% for detecting PVL, n = 4. Recommend using the three best of five trials.

Christy et al., 2014	SVV- the Bucket Test	Test- retest reliability was good, *ICC* = .74, 95% CI [.49, .87], AUC = .55 indicating slightly better than chance prediction of vestibular hypofunction.

Multiple tests as index tests versus cervical vestibular evoked myogenic potential (cVEMP) as reference test. A diagnostic study by Christy et al. (2014) tested the Head Thrust Test (HTT), Emory Clinical Vestibular Chair Test (ECVCT), Bucket Test, Dynamic Visual Acuity (DVA), Modified Clinical Test of Sensory Interaction on Balance (MCTSIB), and the Sensory Organization Test (SOT) as index tests (n = 43) against the cVEMP as the reference test. Among the 43 subjects, 20 subjects had sensioneural hearing loss and of these, three subjects had bilateral vestibular hypofunction (BVH), five had unilateral vestibular hypofunction and 11 had normal vestibular function. All subjects did not complete all tests. Results include area under the curve (*AUC*), where an *AUC* = .50 denotes a 50:50 chance of the test diagnosis the condition correctly (Nordenstrom, 2007). The higher the AUC, the greater the probability the condition is correctly diagnosed. The area under the curve (*AUC*), sensitivity, specificity, positive predictive value (PPV+) and negative predictive value (NPV-) can be seen below. When tests were broken down to test components, such as Modified Emory Clinical Vestibular Chair Test (*m-ECVCT, fixation removed)*, or *SOT visual ratio only, AUC* fell to the .67-.74 range. Therefore, partial testing is not as accurate as completing all portions of the test.

	AUC	Sensitivity	Specificity	Positive Predictive Value [95% CI]	Negative Predictive Value [95% CI]
HTT (positive or negative)	NA	75%	91	.67 [.25, .84]	.83 [31, .90]
MCTSIB Total Score	.89	88%	85%	.78 [026, .89]	.92 [.27, .96]
m-ECVCT fixation removed	.88	63%	100%	1.00 [NA]	.81 [.35, .87]
SOT - vestibular ratio	.88	75%	92%	.86 [.21, .95]	.86 [.33, .91]
DVA	.85	88%	69%	.64 [.27, .96]	.92 [.25, .95]

Note: Cases tested positive on the cVEMP or the Rotary Chair or both. Likelihood ratios were wide because there was a low level of hypofunction in the sample.

VHIT as the index test and Rotary Chair as reference test. The VHIT (n = 33) as the index test with the Rotary Chair Test as the reference standard was reported by Hamilton et al. (2015). It was a retrospective chart review of pediatric subjects who underwent both index and reference test. Of the 33 subjects, eleven diagnoses were included, BPPV (n = 7) was most prevalent, followed by vestibular neuritis (n = 6), congenital peripheral vestibulopathy (n = 4), vestibular migraine (n = 4), chronic subjective dizziness (n = 4), labyrinthine concussion (n = 2), mild traumatic brain injury (n = 2) and one subject in each of the following groups enlarged vestibular aqueduct syndrome, hypothyroidism, spinocerebellar ataxia, and superior semicircular canal dehiscence syndrome. Using multiple linear regression, LSC VHIT gain was a statistically significant predictor of abnormal lateral semicircular canal (LSC) function, $F(3, 52) = 10.692$, $p < .005$. There was no difference between age groups when tested. A gain of <0.7 (cut off value) on the LSC VHIT had a sensitivity of 66.7% and a specificity of 90.9% for detecting LSC function, when Rotary Chair was the reference test. The *AUC* = .9021.

Bruininks Oseretsky Test of Motor Proficiency II (BOT-2) as the index test and multiple tests including caloric testing, rotary chair, and cVEMP) in subjects with SNHL. The BOT-2 (n = 113) was the index test with a group of tests including caloric testing, Rotary Chair, and cVEMP) in pediatric subjects who had undergone cochlear implantation as reference tests. The study was a retrospective review, and subjects who underwent both balance testing and complete evaluation of VD were included. VHIT was added to the evaluation in a minority of the subjects. Hearing loss was caused by a variety of diagnoses, including Usher Syndrome Type 1 (n = 11), abnormal cochlea (n = 8), meningitis (n = 7), homozygous Connexin 26 mutations (n = 1), auditory neuropathy spectrum disorder (n = 1) and unknown (n = 15). The balance subtest of the BOT-2 was the most sensitive and specific tool, AUC = 91%. Individual items on the test had the following *AUC*s: One leg standing, eyes closed, *AUC* = 90.4%; Tandem stance, on a balance beam with eyes open, *AUC* = 82.1%;Tandem stance, eyes closed, *AUC* = 81.9%: One leg standing,

balance beam, eyes open, *AUC* = 74.2%; one leg standing, balance beam, eyes closed, *AUC* = 82.5%; Tandem walking, *AUC* = 73.3%; Tandem stance, eyes open, *AUC* = 64.4%; and Walking on line, *AUC* = 62.2%.

Reliability and Validity.

Reliability of multiple tests as index tests and cVEMP as reference test. Christy et al. (2014) reported the HTT, ECVCT, Bucket Test, DVA, MCTSIB, and the SOT as index tests and the reference test of cVEMP were tested in subjects with SNHL (*n* = 43). Using the intraclass correlation coefficient (ICC) they reported good test- retest reliability for all tests except for condition 4 of the MCTSIB (*ICC* > .73). They reported strong responsiveness of the DVA and MCTSIB, but data was not reported. Interrater reliability was good for m-ECVCT in room light *ICC* = .88, 95% CI [.75, .95], and m-ECVCT fixation removed, *ICC* = .95, 95% CI [.88, .98]. Other tests with good inter-rater reliability are HTT, *ICC* = .73, 95% CI [.53, .85] and DVA score, # optotypes, *ICC* = .81, 95% CI [.66, .9].

Reliability of Clinical Test of Sensory Interaction and Balance (CTSIB) and m-ECVCT. (Dannenbaum et al., 2016) reported on the CTSIB, m-ECVCT, and DVA to determine which test could detect a difference between children with CGG and those who were typically developing. Results were:

- DVA- The weighted κ-coefficient for the DVA scores was 0.35, $p = .0028$, 95% CI [.09-.61], indicating poor test-retest reliability.
- CTSIB- the ICC coefficient for the total CTSIB score was 0.69, $p < .001$, [95% CI, 0.37-0.86], indicating moderate reliability.
- m-ECVCT-
  - Using Frenzel goggles
    - Rotated clockwise, *ICC* = 0.88, 95% CI, [.71-.95], $p < .001$
    - Rotated counterclockwise, *ICC* = 0.84 95% CI, [.64-0.93], $p < .001$
  - Using Visor:
    - Rotated clockwise, *ICC* = 0.82, 95% CI, [.59-.93], $p < .001$
    - Rotated counterclockwise, *ICC* = 0.78 95% CI, [.52-0.91], $p < .001$
  - Indicating good test-retest reliability for both the rotary chair using the goggles and the visor.

Validity No tests for validity were reported

Certainty of the evidence for diagnostic test accuracy and reliability of tests of vestibular disorders. The certainty of the body of evidence was very low, based on risk of bias and applicability of the information to the question being answered. The body of evidence was assessed to have various serious risk of bias. Subject sampling is a high risk in in Hamilton et al. (2015) and Oyewumi et al. (2016). Each employed a retrospective design where only subjects who tested positive for vestibular disorder(s) via the reference test were included. It is unknown if the test discriminates between those with and without the disorder. In Christy et al. (2018) there was only one tester for all tests, therefore tests results would be known when the next test was completed. Imprecision is graded as very serious. Each of the five assessed studies had small number of subjects. Note that in Christy et al. (2014) none of the typically developing subjects were available for at least one of the diagnostic tests. Inconsistency is very serious. As you can see from the diagnoses included in each of the reports, each test of VD may not be useful in all diagnoses of VD. Case in point is Brodsky et al. (2016) who found SVV was most useful in subjects with PVL, but not other diagnoses. Dannenbaum et al. (2016) did not perform tests of diagnostic accuracy but compared the ability of two tests that are not known to be accurate.

Identification of Studies

Search Strategy and Results (see Figure 1)

Records identified through database searching *n* = 47

Additional records identified through other sources *n* = 2

Studies Included in this Review

Citation	Study Type
Brodsky, Cusick, Kenna, and Zhou (2015)	Cohort
Christy et al. (2014)	Diagnostic Test Accuracy
Dannenbaum et al. (2016)	Cohort
Oyewumi et al. (2016)	Cohort

Studies Not Included in this Review with Exclusion Rationale (See Table 2 for a description of all studies)

Citation	Reason for exclusion
Alshehri et al. (2016)	Did not test diagnostic accuracy; tested difference between children and adults
Bachmann, Sipos, Lavender, and Hunter (2018)	Did not test diagnostic accuracy; tested normal children only
Corwin et al. (2018)	The test was completed in the ED to evaluate proportion of neurologically normal children with abnormal vestibular testing.
Doettl, Plyler, McCaslin, and Schay (2015)	Does not test diagnostic accuracy; tested effect of age on tests of oculomotor function
Hulse, Hormann, Servais, Hulse, and Wenzel (2015)	Pilot study. Did not test diagnostic accuracy: tested feasibility of the VHIT
Janky and Givens (2015)	Case control design
Janky and Rodriguez (2018)	Narrative review
Kelly et al. (2018)	Case-control design
Lotfi et al. (2017)	Does not test for diagnostic test accuracy, reliability or validity
MacDougall, Weber, McGarvie, Halmagyi, and Curthoys (2009)	Does not test for diagnostic test accuracy, in adults only
Nair et al. (2017)	Does not test for diagnostic test accuracy; tested scores before and after cochlear implants
Niklasson, Rasmussen, Niklasson, and Norlander (2018)	Narrative review
Orr, Bogg, Fyffe, Lam, and Browne (2018)	Does not differentiate between central and peripheral vestibular disorders
Storey et al. (2017)	Describes differences in therapy types, not test accuracy, reliability or validity
Wenzel et al. (2017)	Exhibits how to modify the VHIT to perform the test in children 5-36 months of age

Methods Used for Appraisal and Synthesis

[a]Review Manager (Higgins & Green, 2011) is a Cochrane Collaborative computer program used to assess the study characteristics as well as the risk of bias and create the forest plots found in this analysis.

[b]Rayyan is a web-based software used for the initial screening of titles and / or abstracts for this analysis (Ouzzani, Hammady, Fedorowicz & Elmagarmid, 2017).

[c]The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) flow diagram depicts the process in which literature is searched,

screened, and eligibility criteria is applied (Moher, Liberati, Tetzlaff, & Altman, 2009).

[d]The Quality Assessment of Diagnostic Accuracy Studies-2 (QUADAS-2) (Whiting et al., 2011) is was used to assess the sources of bias and variation in the diagnostic studies found in this analysis.

[a]Higgins, J. P. T., & Green, S. e. (2011). *Cochrane Handbook for Systematic Reviews of Interventions [updated March 2011]* (Version 5.1.0 ed.): The Cochrane Collaboration, 2011.

[b]Ouzzani, M., Hammady, H., Fedorowicz, Z., & Elmagarmid, A. (2016). Rayyan-a web and mobile app for systematic reviews. *Systematic Reviews, 5*(1), 210. doi:10.1186/s13643-016-0384-4

[c]Moher D, Liberati A, Tetzlaff J, Altman DG, The PRISMA Group (2009). *P*referred *R*eporting *I*tems for *S*ystematic Reviews and *M*eta-*A*nalyses: The PRISMA Statement. PLoS Med 6(7): e1000097. doi:10.1371/journal.pmed1000097 **For more information, visit www.prisma-statement.org.**

[d]Whiting, P. F., Rutjes, A. W., Westwood, M. E., Mallett, S., Deeks, J. J., Reitsma, J. B., ... & Bossuyt, P. M. (2011). QUADAS-2: a revised tool for the quality assessment of diagnostic accuracy studies. *Annals of internal medicine*, *155*(8), 529-536.

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Acronyms Used in this Document

ANOVA	Analysis of Variance
AUC	Area Under the Curve
BOT-2	Bruininks-Oseretsky Test of Motor Proficiency II
BPPV	Benign Paroxysmal Position Vertigo
CAT	Critically Appraised Topic
CV	Central Vertigo
cVEMP	Cervical Vestibular Evoked Myogenic Potential
DTA	Diagnostic Test Accuracy
DVA	Dynamic Visual Acuity
EBP	Evidence Based Practice
ED	Emergency Department
ECVCT	Emory Clinical Vestibular Chair Test
HTT	Head Thrust Test
ICC	Interclass Correlation Coefficient
MCTSIB	Modified Clinical Test of Sensory Interaction on Balance

m-ECVCT	Modified Emory Clinical Vestibular Chair Test
NPV-	Negative Predictive Value
PPV+	Positive Predictive Value
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses
PVL	Peripheral Vestibular Loss
SNHL	Sensorineural Hearing Loss
SOT	Sensory Organization Test
SVV	Subjective Visual Vertical
VEMP	Vestibular evoked myogenic potential
VHIT	Video Head Impulse Test

Table 1

Tests Used to Assess for Vestibular Disorders

Name	Acronym	Application	Source
*Bruininks Oseretsky Test of Motor Proficiency II	BOT-2	Assessment of motor proficiency. Incudes eight sub-tests: (a) fine motor, (b) integration, (c) manual dexterity, (d) upper limb coordination, (e) bilateral coordination, (f) balance, (g) speed, and (h) strength	Oyewumi et al. (2016)
Cervical Vestibular Evoked Myogenic Potential	cVEMP	Assessment of the saccule and inferior vestibular nerve	Christy et al. (2014)
*Dynamic Visual Acuity	DVA	Behavioral assessment of the vestibular-ocular reflex	Christy et al. (2014)
Emory Clinical Vestibular Chair Test	ECVCT	Assessment for nystagmus	Christy et al. (2014)
*Head Thrust Test	HTT	Assessment of corrective saccades	Christy et al. (2014)
*Modified Clinical Test of Sensory Interaction on Balance	MCTSIB	Assessment of balance	Christy et al. (2014)
Modified Emory Clinical Vestibular Chair Test	m-ECVCT	Assessment of nystagmus, uses shorter rotation times (30 s versus 60 s)	Christy et al. (2014)
Rotary Chair -Sinusoidal harmonic acceleration	SHA	Assessment of eye movement	Christy et al. (2014)
Sensory Organization Test	SOT	Assessment of postural control	Christy et al. (2014)
Subjective Visual Vertical	SVV	Ocular motor test	Christy et al. (2014)
Video Head Impulse Test	VHIT	Assessment of gain or angular vestibular ocular reflex - specific semicircular function	Hamilton et al. (2015)

Note: * Denotes tests performed by PTs at CMH. BESS and BERG are also performed by PTs but not found in this literature

Table

Description of Studies Included in the Vestibular Disorders Critically Appraised Topic

Authors, Country	Aim	Sponsoring Department	Number of participants and diagnoses	Included tests	Reported diagnostic test accuracy, reliability, or validity
Included studies					
Brodsky 2015	Determine efficacy of SVV in children	Department of Otolaryngology and Communication Enhancement and the Department of Otology and Laryngology	PVL, *n* = 4 BPPV, *n* = 5 CV, *n* = 7 NVD, *n* = 5 Control, *n* = 12	SVV Rotary chair Bi-thermal water caloric testing	DTA Reliability Validity
Christy 2014	Determine reliability, sensitivity, specificity, predictive values likelihood ratios, and cutoff scores for clinical tests of vestibular function	Department of Physical Therapy	SNHL, n = 20 TD, n = 23	DVA HTT MCTSIB m-ECVCT SOT-VR TD VFT	DTA Reliability Validity
Dannenbaum, 2016,	Determine if the DVA test, CTSIB, and m-ECVCT could detected a difference between children with GDD and those with TD	Department of Physical Therapy	GDD, n = 20 TD, n = 11	DVA CTSIB m-ECVCT	Reliability, test-retest, ICC
Oyewuni 2016	Determine if bilateral VD can be predicted by performance on standardized balance tasks.	Otolaryngology – Head and Neck Surgery Clinic	All subjects had SNHL with cochlear implants N = 65 TBVL, n = 45 Normal vestibular function, n = 20	Caloric testing Video head impulse Rotary chair VEMP Standardized balance test vHIT BOT-2	DTA- Sens, Spec AUC

Authors, Country	Aim	Sponsoring Department	Number of participants and diagnoses	Included tests	Reported diagnostic test accuracy, reliability, or validity
Excluded studies					
Alshehri 2016	Tested the difference between children and adults	Multidisciplinary Concussion program	Concussion, n = 65	• vHIT • Self - reported measures • Gait measures	None
Bachman 2018	Narrative review	Audiology	None	None	None
Corwin 2018	Determines percent of neurologically normal children who have failures on various vestibular and oculomotor tests	Emergency Medicine	N = 295 enrolled n = 267 completed exams	• Vestibular and Oculomotor Assessment includes: dysmetria, nystagmus and smooth pursuits, fast saccades, gaze stability testing, near-point of convergence testing, gait balance testing	None
Doettl 2015	Determine the effect of age on tests of oculomotor function	Audiology and Speech Pathology	N = 63	• Oculomotor VNG assessment	Accuracy measured as the amount of error present for each saccade, averaged.
Hulse 2015	Feasibility of the vHIT Pilot study	Department of Otorhinolaryngology, Head and Neck Surgery	N = 55	• vHIT	None
Janky 2015	Determines age changes in testing, peripheral vestibular system function in children with normal hearing and children with cochlear implants	Audiology	N= 33 n = 11 cochlear implants n = 12 normal hearing	• cVEMP • vHIT • Dynamic gait • Single leg stance • SOT • DVA • Gaze stabilization test • vHIT vs Rotary	Reports correlation coefficients is a small group (n = 11) for validity testing.

Authors, Country	Aim	Sponsoring Department	Number of participants and diagnoses	Included tests	Reported diagnostic test accuracy, reliability, or validity
				chair •	
Janky 2018	Narrative review	Audiology	N = 186	• Rotary Chair • VHIT • Caloric testing	None
Lotfi 2017	Compares rehab program vs no rehab program, does not include VD tests	Audiology	N = 54	• Rotary chair test • BOTMP test • CRT test • SWM test	None
MacDougall 2009				•	None, Adults only
Nair 2017	Pre- and post-cochlear implants, does not report DTAs	Departments of Otolaryngology and Head and Neck Surgery	N = 25	• Static Posturography pre and post placement of cochlear implants	None
Niklasson 2018	Narrative review			•	
Orr 2018	Compares vestibular score in those who tolerate exercise vs. those who do not	Children's Hospital, Exercise and Sports Medicine, and Emergency Medicine	N = 139	• Vestibular ocular motor screening (VOMS) • Modified balance error scoring screening (M-BESS) • Immediate Post-Concussion Assessment and Cognitive Testing (ImPACT) and Graded exercise test (GXT)	• Reports predictors of prolonged recovery. A short exercise duration, < 9 minutes, OR = 3.1, 95% CI [1.2, 8.5] and every increment of one positive M-BESS score increased risk of prolonged recovery, OR = 3.8, 95% CI [2.4, 6.0]. When exercise duration and M-BESS were used, Sensitivity = 83.1% and Specificity =

Authors, Country	Aim	Sponsoring Department	Number of participants and diagnoses	Included tests	Reported diagnostic test accuracy, reliability, or validity
					81.5%, AUC = 92.8% indicating high predictive power. • ImPACT scores and Postconcussion Symptom Scale were not predictive of time to recovery.
Storey 2017	Describes differences in therapy types.				None
Wenzel 2017	Shows how to modify the VHIT to perform the test in children.	Department of Otorhinolaryngology, Head and Neck Surgery	N = 6	• vHit	Reports on software and test set up in very young children.

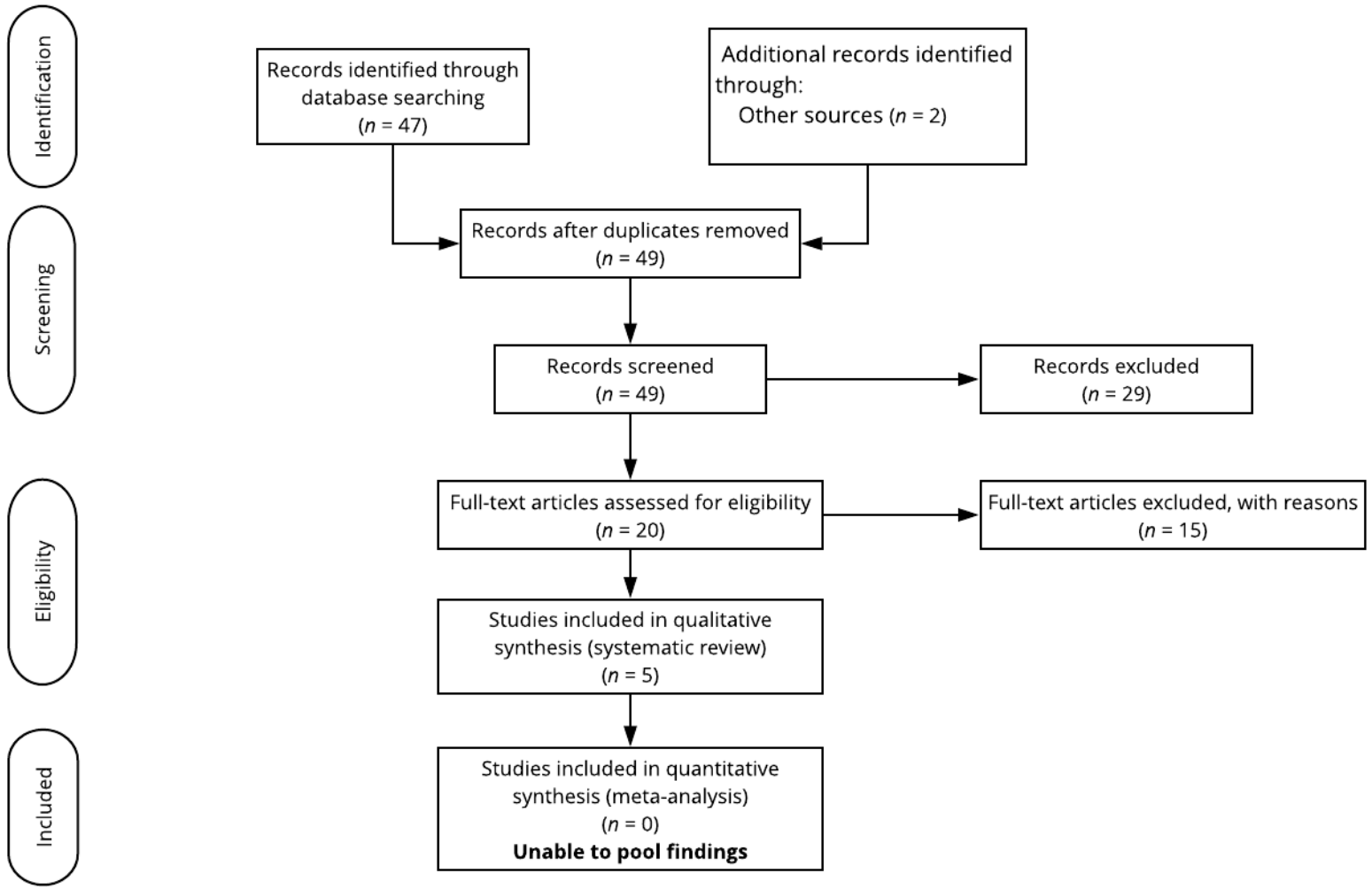

Figure 1. Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRIMSA)[c]

Brodsky et al. (2015)

Patient Sampling[c]	Convenience
Patient characteristics and setting	**Participants:** • Children with and without dizziness **Setting:** Otolaryngology clinic **Number enrolled into the study:** *N* = 33 • Symptom of dizziness, n = 31 • Typically developed, n = 12 **Number completed: the study:** *N* = 33 **Gender, males**: *n* = 33% **Race/ethnicity or nationality (as defined by the researchers):** • Not reported, study was performed in Boston, MA, USA **Age, years, Mean (SD), range** • 13.9 (+/- 2.84), 7-18 years **Exclusion criteria:** • History of chronic middle ear disease • Ear surgery • Brain surgery **Registration:** Not reported
Index test	Static subjective visual vertical (SVV) to identify peripheral vestibular pathology using the Micromedical System 2000 (Micromedical Technologies, Chatham IL)
Target condition and reference standard(s)	Peripheral vestibular loss, reference standard Rotary Chair test or bi-thermal water caloric testing
Flow and timing	Only the subjects with dizziness underwent the reference tests of Rotary Chair testing (*n* = 15) or bi-thermal water caloric testing (*n* = 4). Timing of testing, and if results of tests were known prior to subsequent testing is not reported.
Notes	The reference tests were used to place subjects with dizziness into the following diagnostic categories (a) peripheral vestibular loss, (b) benign paroxysmal positioning vertigo, (c) central vertigo, or (d) non-vestibular dizziness. Four subjects were in the peripheral vestibular loss group. They report that the SVV as significantly higher in the PVL group than in the other groups, however, there are only 4 subjects in the PVL group, and the variation in SVV scores is wide. For example, the range of SVV score in PVL group (*n* = 4) is approximately 0.1 to 3.75. and the variation in the typically developing group (*n* = 12) is approximately 0.2 to 1.5

Patient Selection

A. Risk of Bias	
Was a consecutive or random sample of patients enrolled?	Unclear
Was a case-control design avoided?	Unclear

Did the study avoid inappropriate exclusions?	No
Could the selection of patients have introduced bias?	Unclear risk
B. Concerns regarding applicability	
Are there concerns that the included patients and setting do not match the review question?	Unclear concern

All tests

A. Risk of Bias	
Were the index test results interpreted without knowledge of the results of the reference standard?	Unclear
If a threshold was used, was it pre-specified?	Yes
Could the conduct or interpretation of the index test have introduced bias?	Unclear concern
B. Concerns regarding applicability	
Are there concerns that the index test, its conduct, or interpretation differ from the review question?	High concern

Reference Standard

A. Risk of Bias	
Is the reference standards likely to correctly classify the target condition?	Unclear
Were the reference standard results interpreted without knowledge of the results of the index tests?	Unclear
e	Unclear risk
B. Concerns regarding applicability	
Are there concerns that the target condition as defined by the reference standard does not match the question?	Low concern

Flow and Timing

A. Risk of Bias	
Was there an appropriate interval between index test and reference standard?	Unclear
Did all patients receive the same reference standard?	No
Were all patients included in the analysis?	No
Could the patient flow have introduced bias?	High risk

Christy et al. (2014)

Characteristics of Study	
Methods	**Cohort**
Participants	**Participants:** Children between 6 and 12 years with SNHL **Setting:** Department of Physical Therapy **Number enrolled into study:** *N* = 43 • **Group 1, SNHL:** *n* = 20 • **Group 2, Typically developing (TD):** *n* = 23 **Number completed:** *N* =43 • **Group 1, SNHL:** *n* = 20 • **Group 2, TD:** *n* = 23 **Gender, males: (as defined by researchers)** • · **Group 1, SNHL:** *n* = ·14 (70%) • **Group 2, TD:** *n* = 10 (43%) **Race / ethnicity or nationality (as defined by researchers):** • **White** ○ **SNHL:** *n* = 16 ○ **TD:** *n* = 22 • **African American:** ○ **SNHL:** *n* = 1 ○ **TD:** *n* = 1 • **Hispanic:** ○ **SNHL:** *n* = 1 ○ **TD:** *n* = 0 • **Other:** ○ **SNHL:** *n* = 2 ○ **TD:** *n* = 0 **Age, mean, in years, (SD)** • **Group 1, SNHL:** 8.9 (1.8) • **Group 2, Typically developing:** 9.5 (2.9) **Inclusion criteria:** • Diagnosis of SNHL by audiometric testing **Exclusion criteria:** • Neurological, central visual, or musculoskeletal abnormalities • Fear of darkness • Motion sensitivity • History of neck trauma **Covariates identified:** Not reported
Interventions	**Both:** Order of the five tests is not reported. Testing occurred on three days, of which the last was the reference test

<table>
<tr><td></td><td>performed in an audiology clinic who were blinded to other testing results. All SNHL completed clinical testing, but one did not complete the reference testing. Only two typically developing subjects cervical vestibular testing. Various numbers of

The five tests are:

DVA
HTT
MCTSIB
m-ECVCT
Sensory Organization Test (SOR-VR)

cVEMP to assess the function of the saccule and inferior vestibular nerve
</td></tr>
<tr><td>Outcomes</td><td>Primary outcome(s):
*Reliability and validity of tests·
Secondary outcome(s)
· *Diagnostic test accuracy of the five tests.
Safety outcome(s):
·Not reported</td></tr>
<tr><td>Notes</td><td>Results:
Test-retest reliability ICC >/= .73 for all tests except condition 4 of the MCTSIB, however, it is the same highly trained tester doing the test twice.

The highest overall values for diagnostic test accuracy were for:
<table>
<tr><th></th><th>Sensitivity</th><th>Specificity</th><th>Positive Predictive Value [95% CI]</th><th>Negative Predictive Value [95% CI]</th></tr>
<tr><td>HTT (positive or negative</td><td>75%</td><td>91</td><td>.67 [.25, .84]</td><td>.83 [31, .90]</td></tr>
<tr><td>MCTSIB Total Score</td><td>88%</td><td>85%</td><td>0.78 [026, .89]</td><td>.92 [.27, .96]</td></tr>
<tr><td>m-ECVCT fixation removed</td><td>63%</td><td>100%</td><td>1.00 [NA]</td><td>.81 [.35, .87]</td></tr>
<tr><td>SOT vestibular ratio</td><td>75%</td><td>92%</td><td>.86 [.21, .95]</td><td>.86 [.33, .91]</td></tr>
<tr><td>DVA</td><td>88%</td><td>69%</td><td>.64 [.27, .96]</td><td>.92 [.25, .95]</td></tr>
<tr><td colspan="5">Note: Likelihood ratios were wide because there was a low level of hypofunction in the sample.</td></tr>
</table></td></tr>
</table>

Dannenbaum et al. (2016)

Characteristics of Study	
Methods	**Participants:** **Setting:** Montreal, Quebec, Canada; outpatient pediatric rehabilitation hospital **Number enrolled into study:** *N* = 31 • **Group 1, Case with Global developmental delay (GDD):** *n* = 20 • **Group 2, Aged matched controls, typical developmentally (TD):** *n* =11 **Number completed:** *N* = 29 • **Group 1:** *n* = 18 • **Group 2:** *n* = 11 **Gender, males: (as defined by researchers)** • **Group 1:** *n* = 65% • **Group 2:** *n* = 36% **Race / ethnicity or nationality (as defined by researchers):** • The study occurred in Montreal, Canada. The authors did not identify race or ethnicity of the participants. **Age, mean in years (range)** • **Group 1:** 7.9 (4.4-12.1 years) • **Group 2:** 7.2 (4.7-12.2 years) **Inclusion criteria:** • Children age 3-12 years • Diagnosis of GDD • Sufficient physical, cognitive, and communication capabilities to complete testing procedures **Exclusion criteria:** • Children whose parents did not consent to participation • Children unable to both testing sessions within a 4-week period **Covariates identified:** Not reported
Participants	**Both:** Underwent the following three clinical vestibular tests: • Clinical Test of Sensory Interaction and Balance (CTSIB) • DVA • m-ECVCT • Group 1: Underwent two sessions of testing • Group 2: Were tested only once to provide reference data on the CTSIB and m-ECVCT
Interventions	**Primary outcome:** *To determine which assessment tool could detect a difference between children with GDD and those with TD **Secondary outcome:** *Test-retest reliability for CTSIB, DVA, and m-ECVCT **Safety outcome:** Not reported
Outcomes	**Results:** **Between Group Comparison**

	• CTSIB- the only comparable results that were reported were in the Group 1 one child was able to perform for 30 seconds in the dome on their head standing on foam (DFo) condition compared to 6 children in Group 2 were able to perform for 30 seconds in the DFo condition.
	  ○ Total score was lower in the GDD group than the healthy group ($p < .03$)
	  ○ Eyes closed on the foam (ECFo) and dome covering the head (DF) conditions were significantly lower in the GDD group ($p < .01$)
	• DVA- only Group 1 results were reported for this test. Twelve children in GDD group had a normal DVA score.
	• m-ECVCT- Children with GDD had larger variance in scores than TD subjects.
	Test Retest Reliability in Children with GDD
	• DVA- The weighted κ-coefficient for the DVA scores was 0.35, $p = .0028$, 95% CI [.09-.61], indicating poor test-retest reliability.
	• CTSIB- the ICC coefficient for the total CTSIB score was 0.69, $p < .001$, [95% CI, 0.37-0.86], indicating moderate reliability.
	• m-ECVCT-
	  ○ Using Frenzel goggles
	  ▪ Rotated clockwise, *ICC* = 0.88, 95% CI, [.71-.95], $p < .001$
	  ▪ Rotated counterclockwise, ICC = 0.84 95% CI, [.64-0.93], $p < .001$
	  ○ Using Visor:
	  ▪ Rotated clockwise, *ICC* = 0.82, 95% CI, [.59-.93], $p < .001$----
	  ▪ Rotated counterclockwise, ICC = 0.78 95% CI, [.52-0.91], $p < .001$
	  ○ Indicating good test-retest reliability for both the Rotary Chair using the goggles and the visor.

Hamilton et al. (2015)

Patient Selection

Patient Sampling[c]	Retrospective identification of Pediatric patients who underwent VHIT and Rotary Chair testing
Patient characteristics and setting	**Participants:** • Children who underwent VHIT testing **Setting:** Boston Children's Hospital Program for Balance and Vestibular Research **Number enrolled into the study:** *N* = 33 **Number completed: the study:** *N* = 33 **Gender, males**: 45% **Race/ethnicity or nationality (as defined by the researchers):** • The study occurred in Boston, USA. The authors did not identify race or ethnicity of the participants. **Age, years: Mean (SD), range** • 13 ± (4.3), 3 - 19 **Inclusion criteria: Subjects with** • Semicircular canal dysfunction, such as ○ True rotary vertigo ○ Oscillopsia ○ Severe balance impairment **Exclusion criteria:** • Chronic middle ear disease • Ear surgery • Brain surgery **Registration:** Not reported
Index test	ICS Impulse VHIT
Target condition and reference standard(s)	Vestibular disorder assessed with Rotary Chair testing
Flow and Timing	All testing was done in the past, so flow and timing cannot be assessed. All subjects had VHIT testing and Rotary Chair testing. VHIT testing was performed by a licensed audiologist. It is unclear who did the Rotary Chair testing

Patient Selection

A. Risk of Bias	
Was a consecutive or random sample of patients enrolled?	Unclear
Was a case-control design avoided?	Yes
Did the study avoid inappropriate exclusions?	Yes
Could the selection of patients have introduced bias?	Unclear
B. Concerns regarding applicability	
Are there concerns that the included patients and setting do not match the review question?	Low concern

All tests

A. Risk of Bias	
Were the index test results interpreted without knowledge of the results of the reference standard?	Unclear
If a threshold was used, was it pre-specified?	No
Could the conduct or interpretation of the index test have introduced bias?	Unclear
B. Concerns regarding applicability	
Are there concerns that the index test, its conduct, or interpretation differ from the review question?	Unclear

Reference Standard

A. Risk of Bias	
Target condition and reference standard(s)	Rotary Chair testing
Is the reference standards likely to correctly classify the target condition?	Yes
Were the reference standard results interpreted without knowledge of the results of the index tests?	Unclear
Could the reference standard, its conduct, or its interpretation have introduced bias?	Unclear
B. Concerns regarding applicability	
Are there concerns that the target condition as defined by the reference standard does not match the question?	Unclear

Flow and Timing

A. Risk of Bias	
Flow and timing	All testing was done in the past, so flow and timing cannot be assessed. All subjects had VHIT testing and Rotary Chair testing. VHIT testing was performed by a licensed audiologist. It is unclear who did the Rotary Chair testing
Was there an appropriate interval between index test and reference standard?	Unclear
Did all patients receive the same reference standard?	Yes
Were all patients included in the analysis?	Yes
Could the patient flow have introduced bias?	Unclear risk

Notes: Thirty-three subjects are a low number of subjects, and increases risk for imprecision

Oyewumi et al. (2016)

Methods	Cohort
Participants	**Participants:** Children under the age of 18 years old, with audiological confirmed sever to SNHL. **Setting:** Canada, Head and Neck Surgery clinic **Number enrolled into study:** *N* = 113 • **Group 1, Total bilateral vestibular loss (TBVL):** *n* = 45 • **Group 2, Normal vestibular function:** *n* = 20 **Number completed:** *N* = 113 • **Group 1:** *n* = 45 • **Group 2:** *n* = 20 **Gender, males: (as defined by researchers)** • **Group 1:** *n* = 22 (48.9%) • **Group 2:** *n* = 12 (60%) **Race / ethnicity or nationality (as defined by researchers):** • The study occurred in Canada. The authors did not identify race or ethnicity of the participants. **Age, mean/ years (SD), range** • **Group 1:** 12 years (±3.6), 4.8-18.7 • **Group 2:** 10.7 years (±3.3), 5.6-16.7 **Inclusion criteria:** • Less than18 years old • Audiological confirmed severe to profound SNHL • Underwent complete and standardized evaluation of vestibular and balance function **Exclusion criteria:** • Not meeting criteria of TBVL • Not meeting criteria of normal vestibular function • Partial or unilateral hearing loss **Covariates identified:** All patients had cochlear implants, but the timing of the cochlear implant surgery differed. Most had implants prior to the ability to perform bilateral implantation. Number of subjects who had unilateral vs. bilateral implantation was not reported, nor was a sensitivity analysis performed.

Interventions	**Both:**
	• Standardized balance test occurred during initial clinic evaluation.
	• The balance subset of the BOT-2 was completed. Points assigned for balance in
	  ○ Tandem stance
	  ▪ Eyes open
	  ▪ Eyes closed
	  ○ One-foot standing
	  ▪ Eyes open
	  ▪ Eyes closed
	  ○ Balance Beam

	▪ Tandem stance ▪ Eyes open ▪ Eyes closed
Outcomes	**Primary outcome** • ·Balance test results **Secondary outcome** • Not reported **Safety outcome** • · Not reported
Notes	**Results:** • Tandem stance, eyes open was not statistically different between subjects with TBVL and those with normal vestibular function (p = .13) • For all other conditions listed above on the BOT-2 subtest for balance, subjects with normal vestibular function performs significantly better than those with TBVL (p < .01)

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Appendix

Terms in Tests of Diagnostic Accuracy

Term	Acronym	Definition
Sensitivity (SnNout)	Sn	When a test has a high sensitivity, a negative result rules out the diagnosis
Specificity (SpPin)	Sp	When a test has a high specificity, a positive result rules in the diagnosis
Likelihood ratio for a positive test result	LR+	For a positive test result LR (+) shows how much the odds increase for the presence of disease in cases with a positive result. The highest (LR+) is desired.
Likelihood ratio, for a negative test result	LR-	For a negative test result LR (-) shows how much the odds decrease for the presence of disease in cases with a negative result. The lowest (LR-) is desired.
Predictive value, positive	PV+	The probability of having the disease in a subject with a positive test result
Predictive value, negative	PV-	The probability of not having the disease in a subject with a negative test result
Area Under the Curve	AUC	The ability of a test to predict the desired outcome. An *ACU* of .5 indicates the test has a 50:50 chance of making the correct diagnosis. A higher *AUC* is desired.

Note: Nordenstrom (2007)