1. This document was created to support maximum accessibility for all learners. If you would like to print a hard copy of this document, please follow the general instructions below to print multiple slides on a single page or in black and white.
2. If you are viewing this course as a recorded course after the live webinar, you can use the scroll bar at the bottom of the player window to pause and navigate the course.
3. This handout is for reference only. Non-essential images have been removed for your convenience. Any links included in the handout are current at the time of the live webinar, but are subject to change and may not be current at a later date.
4. Copyright: Images used in this course are used in compliance with copyright laws and where required, permission has been secured to use the images in this course. All use of these images outside of this course may be in violation of copyright laws and is strictly prohibited.

How to print Handouts

- On a PC
  - Open PDF
  - Click Print
  - Choose # of pages per sheet from dropdown menu
  - Choose Black and White from “Color” dropdown
- On a Mac
  - Open PDF in Preview
  - Click File
  - Click Print
  - Click dropdown menu on the right “preview”
  - Click layout
- Choose # of pages per sheet from dropdown menu
- Checkmark Black & White if wanted.
- If more details needed please visit our FAQ page: https://www.audiologyonline.com/help

No part of the materials available through the continued.com site may be copied, photocopied, reproduced, translated or reduced to any electronic medium or machine-readable form, in whole or in part, without prior written consent of continued.com, LLC. Any other reproduction in any form without such written permission is prohibited. All materials contained on this site are protected by United States copyright law and may not be reproduced, distributed, transmitted, displayed, published or broadcast without the prior written permission of continued.com, LLC. Users must not access or use for any commercial purposes any part of the site or any services or materials available through the site.

Technical issues with the Recording?

- Clear browser cache using these instructions
- Switch to another browser
- Use a hardwired Internet connection
- Restart your computer/device

Still having issues?

- Call 800-753-2160 (M-F, 8 AM-8 PM ET)
- Email customerservice@AudiologyOnline.com

CONTINUED SEMINARS IN Hearing

Quantitative Vestibular Function Testing in the Pediatric Population

Kristen Janky, AuD, PhD

Boys Town National Research Hospital

Amanda Rodriguez, AuD, PhD

University of Nebraska - Lincoln

Kristen L. Janky, PhD

Dr. Kristen Janky is Clinical Coordinator of Vestibular Services and Director of the Vestibular and Balance Laboratory at Boys Town National Research Hospital. Her PhD is from the University of Nebraska. She completed a postdoctoral fellowship at Johns Hopkins University. Her research focuses on the effects of vestibular loss in children.

Amanda I. Rodriguez, PhD, AuD

Dr. Amanda Rodriguez is an Assistant Professor and Director of the Concussion and Vestibular Evaluation Laboratory at the University of Nebraska-Lincoln (UNL). She received her AuD-PhD from Texas Tech University and completed a postdoctoral fellowship at Boys Town National Research Hospital. Her research interests include examining the effects of sports concussion on the vestibular system and implications of chronic vestibular loss on behavior and lifestyle. Dr. Rodriguez is a practicing vestibular audiologist and coordinates the vestibular and concussion services for the UNL Barkley Speech, Language, and Hearing Clinic and the Nebraska Athletic Department.

- Presenter Disclosure:
- Kristen L. Janky: Financial: Kristen Janky is employed by Boys Town National Research Hospital. She is a NIH Grant Recipient. She is a consultant for Natus, and an Editor of Balance Function Assessment and Management Textbook. She is a Editorial Board Member of the American Journal of Audiology. She received an honorarium for this presentation. Non-financial: Kristen Janky is President of the American Balance Society.
- Amanda I. Rodriguez: Financial: Amanda Rodriguez in employed by the University of Nebraska- Lincoln. She received NIH T32 post-doc stipend during the time this chapter was written. She received an honorarium for this presentation. Non-financial: Amanda I. Rodriguez is a American Speech, Language, and Hearing Association, Board of Ethics Member.
- Content Disclosure: This learning event does not focus exclusively on any specific product or service.
- Sponsor Disclosure: This course is presented by Seminars in Hearing, a publication of Thieme Medical Publishers, in partnership with AudiologyOnline.

Learning Outcomes

After this course, participants will be able to:

- List which tests of vestibular function are appropriate for children based on their age.
- Describe modifications and considerations that can be made to each test of vestibular function to accommodate children.
- List clinical measures that can be used as screening tools to identify vestibular loss in children.

Introduction

- Prevalence of balance and vestibular disorders in children is variable
    - Risk factors
- Pediatric vestibular testing has challenges for the child and clinician
- Current testing includes assessments for the entire vestibular apparatus
    - Age appropriate
    - Modifications to improve diagnostic capacity

Vestibular Evoked Myogenic Potential (VEMP)

- VEMP is an assessment of otolith function and both branches of the vestibular nerve.
  - ocular VEMP (oVEMP): Mainly Utricular function and Superior Vestibular Nerve
  - cervical VEMP (cVEMP): Saccular function and Inferior Vestibular Nerve

oVEMP

- Contralateral excitatory response activated by a contracted inferior oblique muscle
- Child maintains 30 deg up-gaze
- n10/p16 peak latencies, peak-to-peak amplitudes

cVEMP

- Ipsilateral inhibitory response activated by a contracted SCM
- Child lifts supine/contralateral head turn
- p13/n23 peak latencies, peak-to-peak amplitudes, & tonic EMG level

Vestibular Evoked Myogenic Potential (VEMP)

- Age effects:
  - cVEMP responses can be obtained as soon as 5 days term (Wang et al., 2013) and are reliable between 1-12 month (Sheykholeslami et al., 2005)
    - Children have earlier p13 and/or n23 latencies; however, they become more adult-like after late adolescence (e.g., Sheykholeslami et al., 2005; Kelsch et al., 2006).
  - oVEMP responses can be obtained by age 2, with increased reliability and adult-like amplitudes and latencies by ages 3-4 (Wang et al., 2013; Young et al., 2015; Hsu et al., 2009; Chou et al., 2012).

Vestibular Evoked Myogenic Potential (VEMP)

- **Benefit** of VEMP in children:
  - Does not induce dizziness
  - Can sit with/ close to parent and not in the dark
  - Testing is fast (about 10 – 15 minutes)
  - Ear and otolith specific diagnostic info
- **Challenges** of VEMP in children:
  - Variability in VEMP response as a function of insufficient muscle contraction, electrode placement/intolerance, age, and ear canal size differences.

Vestibular Evoked Myogenic Potential (VEMP)

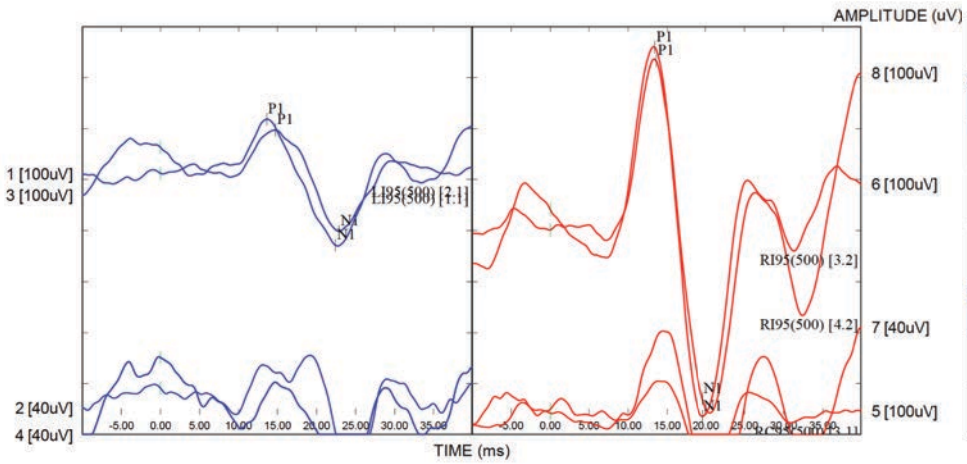
- Modifications for children:
  - Shorten test time:
    - Bilateral stimulation, bone conduction
  - Electrode tolerance:
    - one reference (e.g., chin)
    - oVEMP montage AFTER cVEMP
  - Maintain adequate up-gaze or SCM contraction:
    - Body position and EMG monitoring
    - Play a video, stickers
  - Ensure safe dB SPL
    - 120 dB SPL if ECV is < 0.8 mL
    - Use 750 Hz TB
    - Ascending threshold approach

VEMP: Case Study

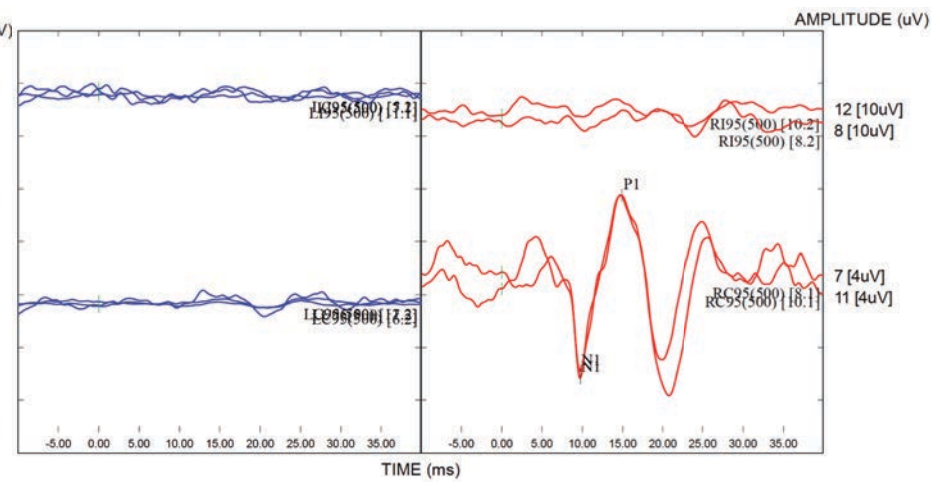
- 5 year old male:
  - Normal hearing in the right ear and a moderately severe sensorineural hearing loss in the left ear, 7 months following MVA with otic-capsule involving temporal bone fracture
  - No prenatal or pre-injury risk factors
  - Parent concern for new change balance, desire and ability to ride a bike, and read.

VEMP: Case Study

- Positive bedside head thrust to the left
- asymmetrical left cVEMP ratio (78%)
- absent left oVEMP



cVEMP



oVEMP

Vestibular Evoked Myogenic Potential (VEMP)

- Summary:
  - cVEMP can be done in newborns (Wang et al. 2008), oVEMP can be done in children 3 and + years, reliably (Hsu et al., 2009; Chou et al., 2012).
  - Expect more variability in responses due to inadequate muscle contraction
  - Employ strategies like EMG monitoring (for cVEMP) or using interesting toys/videos to maintain eye/body position
  - Be mindful of smaller ear canals and effects on SPL and hearing if using AC stimuli

Video Head Impulse Testing (vHIT)

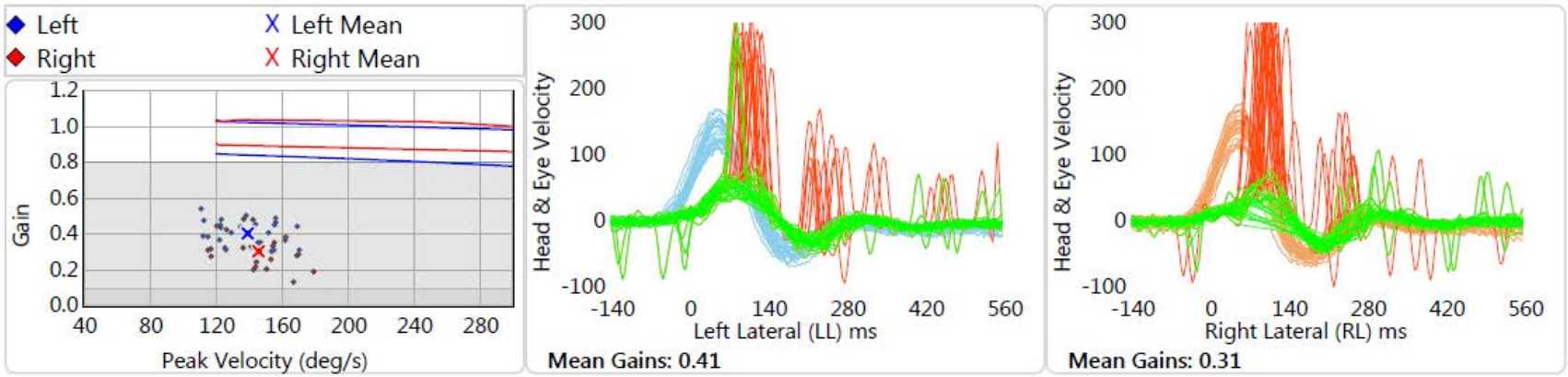
- vHIT is an assessment of individual semicircular canal function and both branches of the vestibular nerve.
  - Horizontal and Anterior canal vHIT: Superior Vestibular Nerve
  - Posterior canal vHIT: Inferior Vestibular Nerve

Video Head Impulse Testing (vHIT)

- Patients fixate on a stable visual target
- Camera measures eye velocity, gyroscope measures head velocity
- Head velocity
  - > 150 d/s horizontal canal
  - > 100 d/s vertical canals

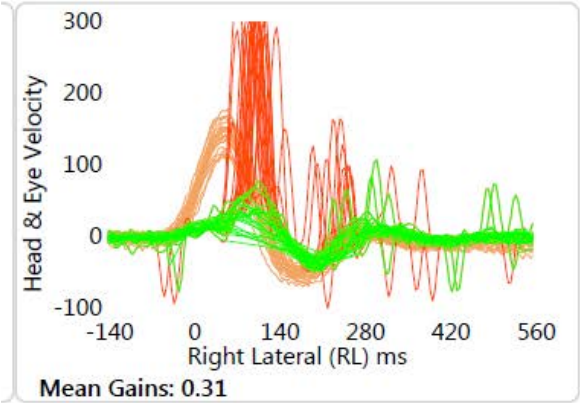
Video Head Impulse Testing (vHIT)

- Similar to adults,
  - 2 Primary Outcome Parameters:
    - Gain: Ratio of eye velocity/head velocity
    - Corrective Saccades

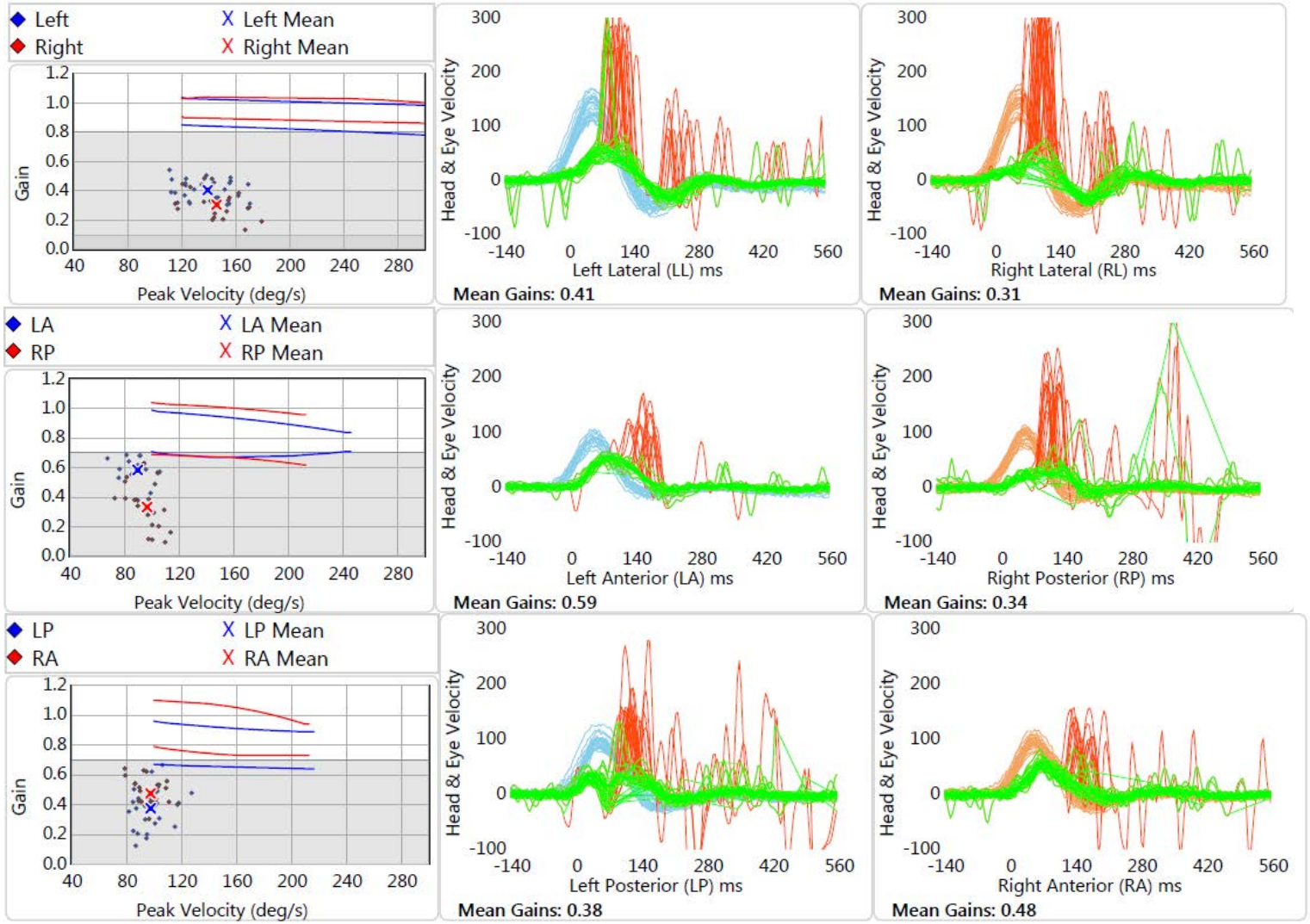


Video Head Impulse Testing (vHIT)

- Gain:
  - Set Gain cut-off of ~ 0.8
  - HOWEVER, there is evidence that vestibular loss is present even with gain at or above 0.8
    - Janky 2018; Korsager 2017; Matino-Soler 2014
- Corrective Saccades:
  - Frequency (50 – 80%)
  - Velocity (> 100)
  - Latency (< 320 ms)
  - Standard Deviation of the latency



Video Head Impulse Testing (vHIT)



Video Head Impulse Testing (vHIT)

- Does vHIT gain change with age?
- Gain reductions in the 8th or 9th decade (Davalos-Bichara 2014; Matino-Soler 2015; McGarvie 2015; Mossman 2015)
  - In children:
    - Many studies report NO CHANGE with age (Janky 2015; Hamilton 2015; Lehnen 2017; Ross 2016)
    - Wiener-Vacher (2017) showed a rapid increase in gain from age 3 to 6 years and then a slow increase up to 16 year

Video Head Impulse Testing (vHIT)

- Benefit of vHIT in children:
  - Does not induce dizziness.
  - Vision is not occluded, so not as scary
  - Test administration is fast (10 – 15 minutes)
  - Can be completed regardless of middle ear status (PE tubes, perforations, mastoid cavity, etc)
  - Ear and canal specific
- Challenges in children:
  - Loose goggles, inability to follow directions, frequency eye blinks, wandering gaze, decreased attention span, noncompliance, apprehension, longer test duration

Video Head Impulse Testing (vHIT)

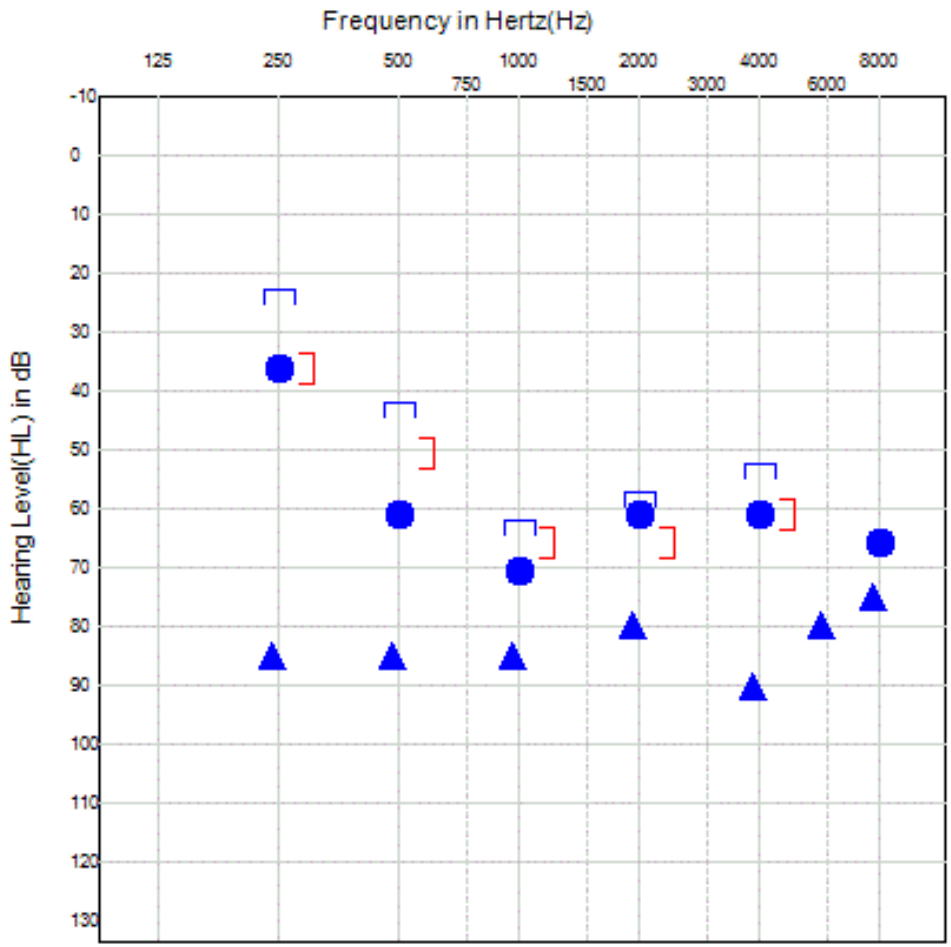
- Modifications for testing children:
  - Loose fitting goggles:
    - Remote video detection:
      - Youngest – 3 months
      - (Wiener-Vacher & Wiener 2017)
  - Sustained Gaze / inattention
    - Foam
    - iPhone
    - Stickers

Video Head Impulse Testing (vHIT)

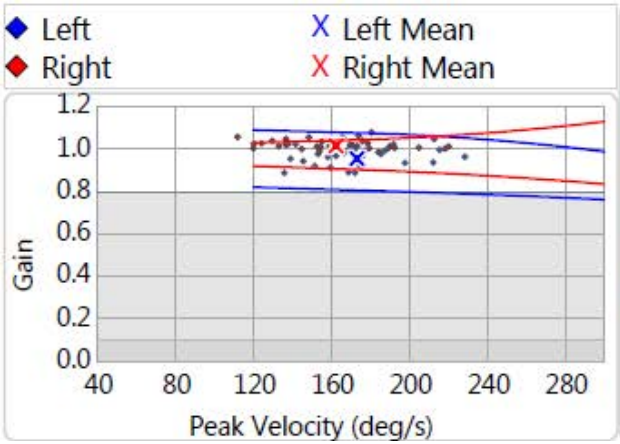
- Summary:
  - Children > 3 months can use a remote system
  - Children > 3 years can use a traditional goggle system
  - Use a fun target for attention
  - You may not get as many responses
  - It's going to take longer (Hulse 2015).
  - The data is not going to be as clean.
  - vHIT is a reliable test of semicircular canal function and can be completed in children age 3 and up
    - (Ross 2016; Hamilton 2015; Hulse 2015).

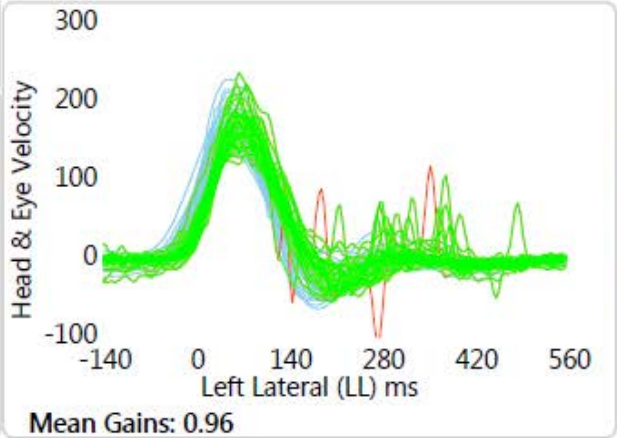
vHIT: Case Study

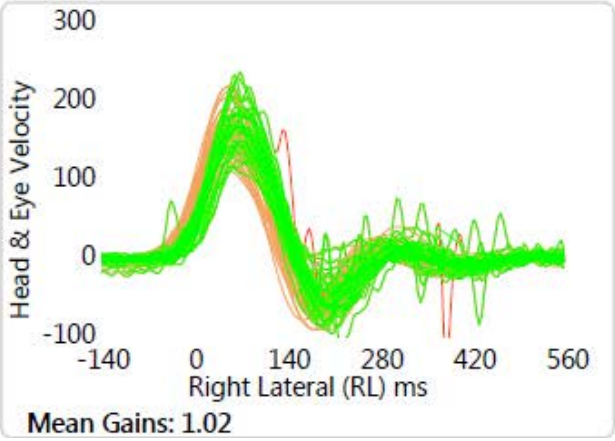
- 12-year old male
  - 2 – 3 times per year patient reports dizziness in conjunction with nausea, vomiting, and headaches.
  - Congenital hearing loss
  - Perforation in left ear

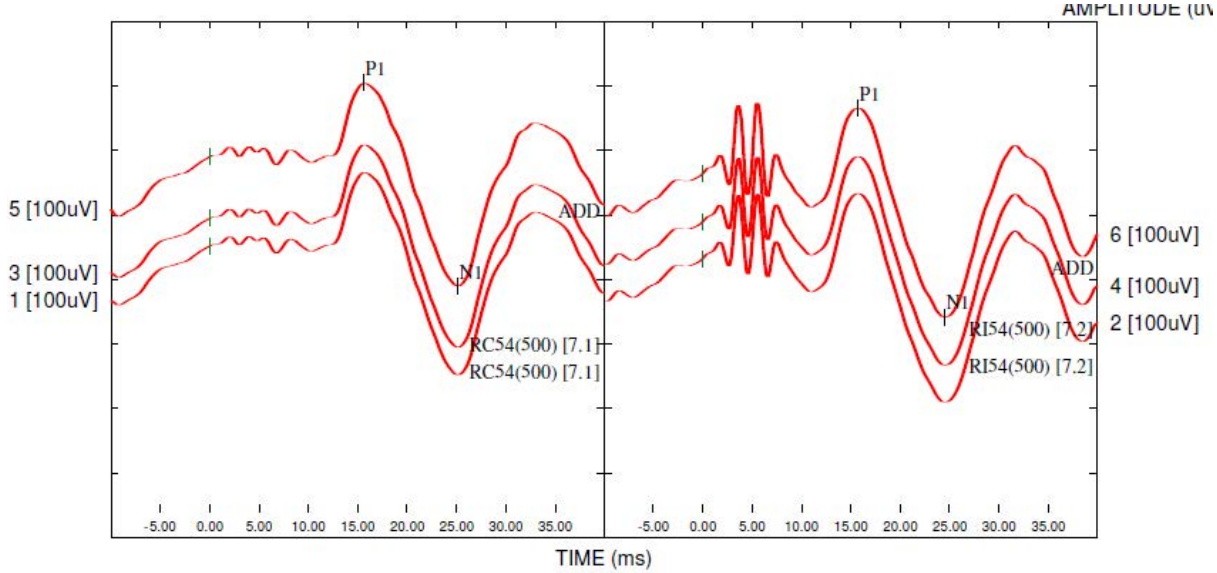


vHIT: Case Study









Rotary Chair

- Rotary chair testing takes ~ 10 to 15 minutes
- A midfrequency (0.01–0.64 Hz) assessment of the horizontal canal and superior branch of the vestibular nerve.
- 2 Paradigms:
  - Sinusoidal Harmonic Acceleration:
  - Step test

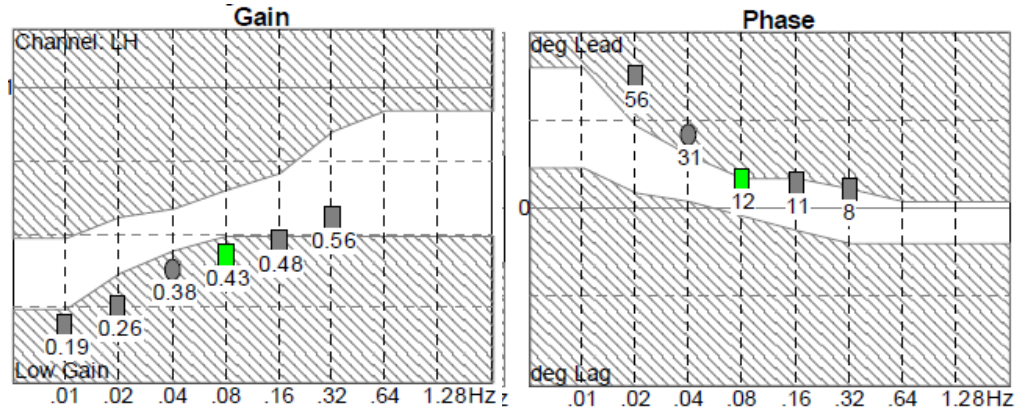
Rotary Chair

- Benefit of Rotary chair in children:
  - Most common assessment Children > 2 months, but < 5 years (Use vHIT at age 3 years)
  - Does not provide ear specific info, but is the only test of canal function for some children < 3 years
  - < 15 minutes to complete
  - Tolerated by most children
  - Reliable in children
  - Not affected by middle ear status
    - EXCEPT: middle ear effusion
    - Complete tympanometry prior to

Rotary Chair

- Challenges when testing children:
  - Outcomes: Gain, Phase (time constant), Symmetry
    - Gain: Decreasing gain, increasing gain, and no change in gain have been reported with age in children.
    - In children with normal vestibular function, high rotary chair gains have consistently been reported compared with adults (Charpiot et al., 2010; Maes, De Kegel, Van, & Dhooge, 2014; Valente, 2007); therefore, high gain in young children is not considered a pathologic finding unless coupled with other indications for central pathology.
    - Recommend to generate your own norms; or interpret your findings with regard to the manufacturer norms keeping these trends in mind.

Rotary Chair



- Similar to adults, gain less than 0.01 with phase greater than 68 degrees in response to 0.01 Hz during SHA testing suggests bilateral vestibular loss (Strupp et al., 2017)
- > 2 months
  - 10% of infants less than 60 days old do not generate measurable nystagmus (Staller et al., 1986)
  - Lack of responses is more likely in children with low birth weight.

Rotary Chair

- Challenges when testing children:
  - Goggle fit
  - Electrode fit
  - Car seat vs sitting in parent's lap
  - Intolerant
  - Attention
  - Communicating when children have hearing loss

Rotary Chair

- Modifications for testing children:
  - ATTENTION:
    - a typical order of testing would be 0.04, 0.01, 0.16 Hz for a mid, low, and high frequency assessment.
    - If the child is still cooperative, 0.02 and 0.08 Hz would be completed
    - Parents can place a hand over the child's head to maintain head placement, ensure that electrodes are not removed, and assist with keeping the child awake and alert.
    - If infants do not tolerate wearing electrodes, a subjective assessment of nystagmus can be completed via the infrared video monitor.
    - Parents or examiner can sing songs

Rotary Chair

- Modifications for testing children:
  - EFFUSION:
    - Complete tympanometry prior to testing
  - MATURATION:
    - If children < 9 months do not elicit nystagmus to rotation, testing should be repeated to rule out maturational effects (Eviatar 1979).
  - INTOLERANCE
    - For older children who choose to ride alone but are scared to rotate in the dark, the rotary chair door can be kept open while the child closes their eyes during rotation, using electrodes to monitor eye movements

Rotary Chair

- Modifications for testing children:
  - HEARING LOSS:
    - Wear hearing aids during assessment
    - a co-riding parent provide alerting tasks to the child at a close range
    - alerting tasks are discussed prior to closing the rotary chair door.

Rotary Chair

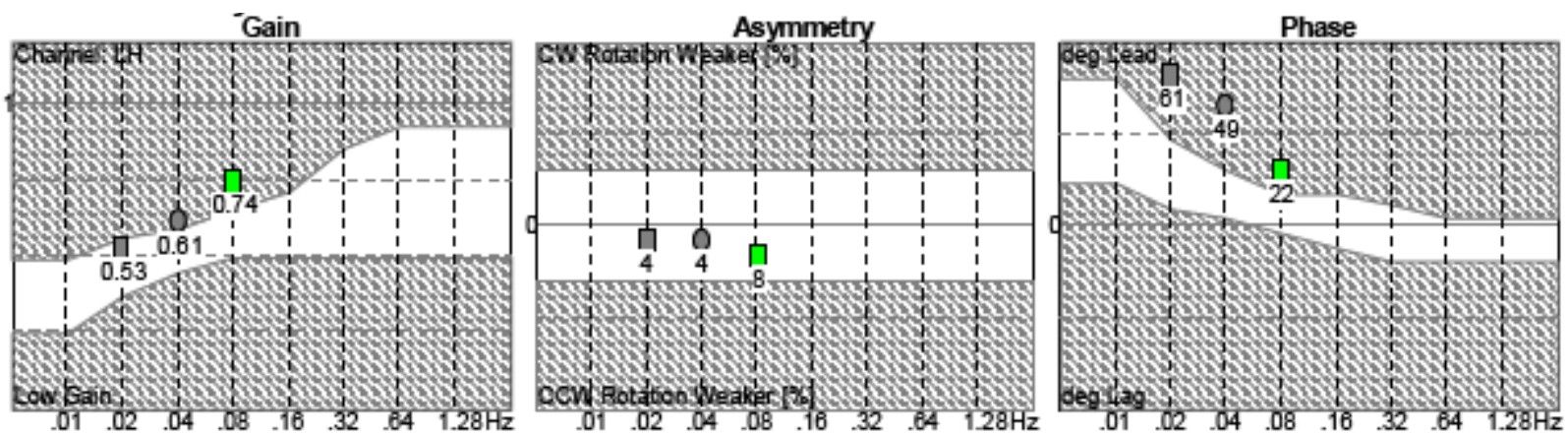
- Summary:
  - Appropriate for children > 2 months
  - Generate your own data
  - Assess Low (0.01 Hz), Mid (0.04 Hz) and High (0.16 Hz)
  - If nystagmus is not measured in children less than 9 months of age, rotary chair should be repeated.
  - Attention and alertness can significantly affect rotary chair gain; therefore, clinicians should use strategies to keep the child awake and alert.

Rotary Chair: Case Study

- 14 month old female:
  - Normal hearing in the right ear and a profound sensorineural hearing loss in the left ear.
  - Mother reported some concerns for balance
  - The patient began sitting unassisted at 8 months
  - History of ear infections was denied.
  - Seen for determination of hearing loss etiology
- Risk Factors:
  - Gross motor delay
  - Degree of hearing loss

Rotary Chair: Case Study

- Phase lead at all test frequencies; consistent with peripheral vestibular system involvement without localization to the right or left.
- Left side of localization would more likely given the profound sensorineural hearing loss in the left ear.
- MRI: Congenital absence of left vestibular nerve



Caloric Testing

- Gold standard of vestibular system testing
- Similar to adults, children lie supine, with their head elevated ~ 30 degrees
  - Cool (30°C) and warm (44°C) irrigations in each ear.
  - 30 seconds each for water and 60 each for air.
- Electrodes or infrared goggles record eye movements.
- Takes ~ 20 to 25 minutes to complete
- Low-frequency (0.002 Hz) assessment of horizontal canal and superior branch of vestibular nerve.

Caloric Testing

- Caloric response mature at age 6 – 12 months; however, caloric testing is not routine in pediatric vestibular testing until children are > 6 to 7 years.
- Slow phase velocity decreases from age 2 to 10 years.

- Benefit of Rotary chair in children:
  - Ear specific, low frequency information
  - vHIT and rotary chair are insensitive to mild vestibular loss – best assessment for mild, unilateral vestibular loss

Caloric Testing

- Challenges when testing children:
  - Scary for children
  - Induces dizziness
  - Hearing is temporarily disrupted by water/air
  - Children need to lie still for duration of testing
  - Affected by middle ear pathology
  - Goggle fit
  - Attention

Caloric Testing

- Modifications for testing children:
  - Reinforcement / Reassurance
  - Parents can hold child's hand
  - Duration of irrigation can be reduced from 30 to 20 seconds
  - Complete Monothermal irrigations
  - Singing songs

Caloric Testing

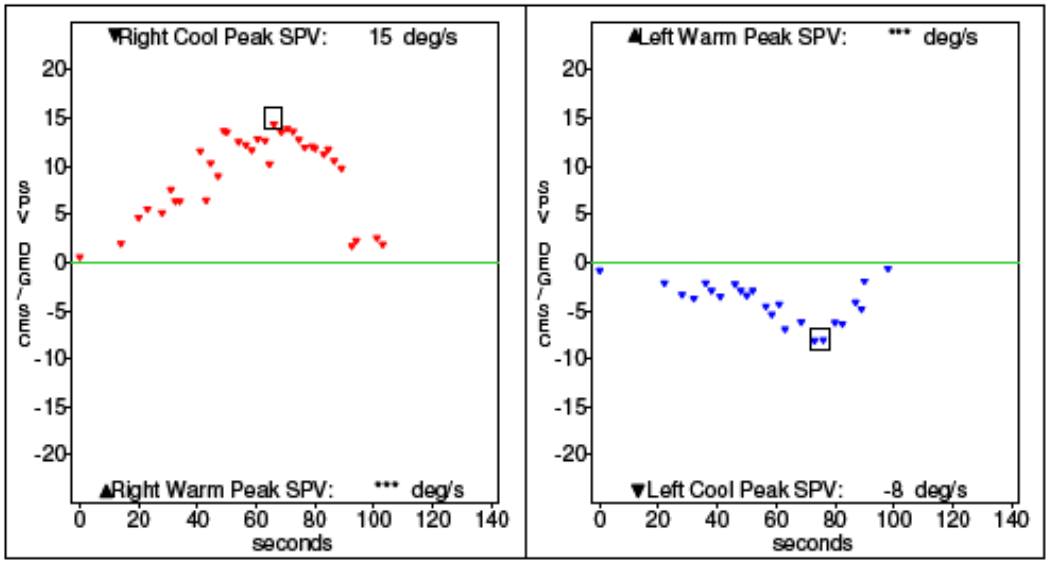
- Summary:
  - Completed starting at age 6 – 7 years
  - vHIT recommended as first tier assessment, if normal caloric can be completed – monothermal, at minimum.

Caloric Testing: Case Study

- 14 year-old female
  - Patient chief complaint is an episode of true vertigo which caused an inability to stand and nausea.
  - Symptoms lasted several hours. She went to the ER and was given meclizine.
  - Since the episode, she reports occasional bouts of nausea, which last for minutes at a time.
  - Three years ago, she experienced sudden hearing loss in her left ear. She denies dizziness at the time of the hearing loss. Additionally, she denies a change in hearing, tinnitus, and pain with recent episode of vertigo.

Caloric Testing: Case Study

- Findings demonstrate left peripheral vestibular system involvement given borderline caloric weakness (30%) and absent cervical and ocular vestibular evoked myogenic potential (VEMP) in the left ear.



Screening

- Do you suspect a child may have vestibular loss?
  - A few simple screening tests can be completed to help rule out vestibular loss.
    - Case history, including age of gross motor attainment, and severity of hearing loss
    - modified clinical test of sensory integration on balance,
    - the bedside head thrust test,
    - the Emory clinical vestibular chair test,
    - the dynamic visual acuity test,
    - single-leg stance,
    - tandem standing,

Q9

Screening

- Case history:
  - Presence of hearing loss?
    - Compute the bilateral pure tone average for 250, 1,000, 2,000, and 4,000 Hz
    - CUT-OFF SCORE: 40 dB, sensitivity = 80%, specificity = 55%
    - CUT-OFF SCORE: 66 dB, sensitivity = 33%, specificity = 91%
  - Concerns regarding gross motor delay?
  - Age the child sat
    - CUT-OFF SCORE: > 7 mos, sensitivity = 62%, specificity = 81%
  - Age the child walked independently
    - CUT-OFF SCORE: > 14 mos, sensitivity = 78%, specificity = 77%

Screening

- Single Leg Stance
  - Stand on dominate leg with nondominant leg raised, knee bent to 90 degrees, hands on hips, and eyes closed for a maximum of 10 s. Timing is stopped if eyes open, foot is put down, or standing leg is moved
    - CUT-OFF: < 4 seconds, sensitivity = 90%, specificity = 100%
- mCTSIB
  - Maintain balance with arms crossed against chest for 30 s while (1) standing, eyes open; (2) standing, eyes closed; (3) standing on foam, eyes open; (4) standing on foam, eyes closed. Maximum score is 120 s
    - CUT-OFF: 100 s, sensitivity = 88%, specificity = 85%

Screening

- Bedside Head Thrust Test
  - The head is tilted 30 degrees downward and high acceleration, unpredictable head thrusts are delivered in the plane of each horizontal canal
    - CUT-OFF: corrective saccade, sensitivity = 75%, specificity = 91%

Screening

- Summary:
  - Screening can be completed in minutes
    - Case History: Gross motor function
    - Audiogram review: severity of hearing loss
    - Single leg stance: < 30 seconds
    - Bedside Head impulse test: < 30 seconds
    - OTHERS:
      - Dynamic visual acuity
      - mCTSIB
      - Tandem stance
      - Emory clinical vestibular chair test

Pediatric Vestibular Questionnaires

- Children don't always report sx consistent with vestibular loss
- Pediatric Questionnaires can quantify impact of symptoms on daily activities

Pediatric Vestibular Questionnaires

- *Dizziness Handicap Inventory for parents and caregivers*, ages 5-12
  - 21 items
  - completed by parent/caregiver
- *Pediatric Vestibular Symptom Questionnaire,* ages 6-17
  - 11 items
  - child-reported
  - severity of sx, related to balance, dizziness, vertigo
- *Pediatric Visually Induced Dizziness Questionnaire*, ages 6-17
  - 11 items
  - child-reported
  - severity of sx, related to visual situations

Summary

- Pediatric vestibular testing can be helpful for children most at-risk
  - HL, CI's, gross motor delay, complaints of dizziness, and/or + screening
  - When age-appropriate, vestibular testing can be modified in various ways to improve compliance and test results
  - Screenings can be helpful to build a case for vestibular referral
  - Questionnaires can quantify severity of functional impact

Questions?

Thank you!

References

- O'Reilly RC, Morlet T, Nicholas BD, et al. Prevalence of vestibular and balance disorders in children. Otol Neurotol 2010;31(09):1441–1444
- Li CM, Hoffman HJ,Ward BK, Cohen HS, Rine RM. Epidemiology of dizziness and balance problems in children in the United States: a population based study. J Pediatr 2016;171:240–7.e1, 3
- Inoue A, Iwasaki S, Ushio M, et al. Effect of vestibular dysfunction on the development of gross motor function in children with profound hearing loss. Audiol Neurootol 2013;18(03):143–151
- Kaga K, Shinjo Y, Jin Y, Takegoshi H. Vestibular failure in children with congenital deafness. Int J Audiol 2008;47(09):590–599
- O'Reilly RC, Greywoode J, Morlet T, et al. Comprehensive vestibular and balance testing in the dizzy pediatric population. Otolaryngol Head Neck Surg 2011;144(02):142–148
- Basta D, Todt I, Goepel F, Ernst A. Loss of saccular function after cochlear implantation: the diagnostic impact of intracochlear electrically elicited vestibular evoked myogenic potentials. Audiol Neurootol 2008;13(03):187–192

References

- Cushing SL, Papsin BC, Rutka JA, James AL,Gordon KA. Evidence of vestibular and balance dysfunction in children with profound sensorineural hearing loss using cochlear implants. Laryngoscope 2008;118(10):1814–1823
- Licameli G, Zhou G, Kenna MA. Disturbance of vestibular function attributable to cochlear implantation in children. Laryngoscope 2009;119(04): 740–745
- Colebatch JG, Halmagyi GM. Vestibular evoked potentials in human neck muscles before and after unilateral vestibular deafferentation. Neurology 1992;42(08):1635–1636
- Colebatch JG, Halmagyi GM, Skuse NF. Myogenic potentials generated by a click-evoked vestibulocollic reflex. J Neurol Neurosurg Psychiatry 1994; 57(02):190–197
- Robertson DD, IrelandDJ. Vestibular evoked myogenic potentials. J Otolaryngol 1995;24(01):3–8
- Rosengren SM, McAngus Todd NP, Colebatch JG. Vestibular-evoked extraocular potentials produced by stimulation with bone-conducted sound. Clin Neurophysiol 2005;116(08):1938–1948
- Todd NP, Rosengren SM, Colebatch JG. A short latency vestibular evoked potential (VsEP) produced by bone-conducted acoustic stimulation. J Acoust Soc Am 2003;114(6, Pt 1):3264–3272

References

- Todd NP, Rosengren SM, Aw ST, Colebatch JG. Ocular vestibular evoked myogenic potentials (OVEMPs) produced by air- and bone-conducted sound. Clin Neurophysiol 2007;118(02):381–390
- Weber KP, Rosengren SM, Michels R, Sturm V, Straumann D, Landau K. Singlemotor unit activity in human extraocular muscles during the vestibulo-ocular reflex. J Physiol 2012;590:3091-3101.
- Curthoys IS, Iwasaki S, Chihara Y et al. The ocular vestibular-evoked myogenic potential to air-conducted sound; probable superior vestibular nerve origin. Clin Neurophysiol 2011;122:611-616.
- Makowiec K, McCaslin DL, Jacobson GP et al. Effect of Electrode Montage and Head Position on Air-Conducted Ocular Vestibular Evoked Myogenic Potential. Am J Audiol 2017;26:180-188.
- Papathanasiou ES, Murofushi T, Akin FW et al. International guidelines for the clinical application of cervical vestibular evoked myogenic potentials: an expert consensus report. Clin Neurophysiol 2014;125:658-666.
- McCaslin DL, Jacobson GP, Hatton K et al. The effects of amplitude normalization and EMG targets on cVEMP interaural amplitude asymmetry. Ear Hear 2013;34:482-490.

References

- Bogle JM, Zapala DA, Criter R et al. The effect of muscle contraction level on the cervical vestibular evoked myogenic potential (cVEMP): usefulness of amplitude normalization. J Am Acad Audiol 2013;24:77-88.
- McCaslin DL, Fowler A, Jacobson GP. Amplitude normalization reduces cervical vestibular evoked myogenic potential (cVEMP) amplitude asymmetries in normal subjects: proof of concept. J Am Acad Audiol 2014;25:268-277.
- Isaradisaikul S, Navacharoen N, Hanprasertpong C et al. Cervical vestibular-evoked myogenic potentials: norms and protocols. Int J Otolaryngol 2012;2012:913515.
- Wang SJ, Chen CN, Hsieh WS et al. Development of vestibular evoked myogenic potentials in preterm neonates. Audiol Neurootol 2008;13:145-152.
- Sheykholeslami K, Megerian CA, Arnold JE et al. Vestibular-evoked myogenic potentials in infancy and early childhood. Laryngoscope 2005;115:1440-1444.
- Kelsch TA, Schaefer LA, Esquivel CR. Vestibular evoked myogenic potentials in young children: test parameters and normative data. Laryngoscope 2006;116:895-900.
- Maes L, De Kegel A, Van WH et al. Rotatory and colic vestibular evoked myogenic potential testing in normal-hearing and hearing-impaired children. Ear and Hearing 2014.

References

- Rodriguez, AI, Thomas, MLA, Fitzpatrick, D, Janky, KL (2018). Effects of high sound pressure exposure during air-conducted vestibular evoked myogenic potential testing in children and young adults. *Ear Hear*. *39*(2):269-277.
- Zhou G, Kenna MA, Stevens K et al. Assessment of saccular function in children with sensorineural hearing loss. Arch Otolaryngol Head Neck Surg 2009;135:40-44.
- Rodriguez, AI, Thomas, MLA, Janky, KL (2019). Air-conducted vestibular evoked myogenic potential testing in children, adolescents and young adults: Thresholds, frequency tuning, and effects of sound exposure. *Ear Hear*. 39(2), 269-277.
- Taylor RL, Bradshaw AP, Magnussen JS et al. Augmented ocular vestibular evoked myogenic potentials to air-conducted sound in large vestibular aqueduct syndrome. Ear Hear 2012;33:768-771.
- Taylor RL, Bradshaw AP, Halmagyi GM et al. Tuning characteristics of ocular and cervical vestibular evoked myogenic potentials in intact and dehiscent ears. Audiol Neurootol 2012;17:207-218.
- Valente M. Maturational effects of the vestibular system: a study of rotary chair, computerized dynamic posturography, and vestibular evoked myogenic potentials with children. J Am Acad Audiol 2007;18:461-481.

References

- Janky KL, Givens D. Vestibular, Visual Acuity, and Balance Outcomes in Children With Cochlear Implants: A Preliminary Report. Ear Hear 2015;36:e364-e372.
- Young YH. Assessment of functional development of the otolithic system in growing children: a review. Int J Pediatr Otorhinolaryngol 2015;79:435-442.
- Wang SJ, Hsieh WS, Young YH. Development of ocular vestibular-evoked myogenic potentials in small children. Laryngoscope 2013;123:512-517.
- Hsu YS, Wang SJ, Young YH. Ocular vestibular-evoked myogenic potentials in children using air conducted sound stimulation. Clin Neurophysiol 2009;120:1381-1385.
- Chou CH, Hsu WC, Young YH. Ocular vestibular-evoked myogenic potentials via bone-conducted vibration in children. Clin Neurophysiol 2012;123:1880-1885.
- Piker EG, Jacobson GP, McCaslin DL et al. Normal characteristics of the ocular vestibular evoked myogenic potential. J Am Acad Audiol 2011;22:222-230.
- Cushing SL, Papsin BC, Rutka JA et al. Vestibular end-organ and balance deficits after meningitis and cochlear implantation in children correlate poorly with functional outcome. Otol Neurotol 2009;30:488-495.

References

- Fuemmeler, E, Rodriguez, AI, Thomas, MLA, Creutz, T, Fitzpatrick, D, Janky, KL (*in press*). Vestibular evoked myogenic potential (VEMP) test-retest reliability in children. *OtolNeur*.
- Young YH. Vestibular evoked myogenic potentials: optimal stimulation and clinical application. J Biomed Sci 2006;13:745-751.
- Krause E, Mayerhofer A, Gurkov R et al. Effects of acoustic stimuli used for vestibular evoked myogenic potential studies on the cochlear function. Otol Neurotol 2013;34:1186-1192.
- Stromberg AK, Olofsson A, Westin M et al. Changes in cochlear function related to acoustic stimulation of cervical vestibular evoked myogenic potential stimulation. Hear Res 2016;340:43-49.
- Mattingly JK, Portnuff CD, Hondorp BM et al. Sudden Bilateral Hearing Loss After Cervical and Ocular Vestibular Evoked Myogenic Potentials. Otol Neurotol 2015;36:961-964.
- Thomas MLA, Fitzpatrick D, McCreery R et al. Big Stimulus, Little Ears: Safety in Administering Vestibular-Evoked Myogenic Potentials in Children. J Am Acad Audiol 2017;28:395-403.
- Chen CN, Wang SJ, Wang CT et al. Vestibular evoked myogenic potentials in newborns. Audiol Neurootol 2007;12:59-63.

References

- Salloway, SP. Rooting Reflex. In: Kreutzer J, DeLuca J, Caplan B, eds. Encyclopedia of Clinical Neuropsychology. New York, NY: Springer, 2011: 161-173.
- Yang CJ, Lavender V, Meinzen-Derr JK et al. Vestibular pathology in children with enlarged vestibular aqueduct. Laryngoscope 2016;126:2344-2350.
- Govender S, Rosengren SM, Colebatch JG. The effect of gaze direction on the ocular vestibular evoked myogenic potential produced by air-conducted sound. Clin Neurophysiol 2009;120:1386-1391.
- Huang YC, Yang TL, Young YH. Feasibility of ocular vestibular-evoked myogenic potentials (oVEMPs) recorded with eyes closed. Clin Neurophysiol 2012;123:376-381.
- Colebatch JG, Rosengren SM. Safe levels of acoustic stimulation: comment on '"effects of acoustic stimuli used for vestibular evoked myogenic potential studies on the cochlear function. Otol Neurotol 2014;35:932-933.
- European Union. Directive 2003/10/EC of the European Parliament and of the Council on the minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (noise) (Seventeenth individual Directive within the meaning of Article 16(1) of Directive 89/ 391/EEC). Official Journal L 2003;042:0038-0044.

References

- Rodriguez, AI, Marler, E, Fitzpatrick, D, Creutz, T, Cannon, SA, Thomas, MLA, **Janky, KL** (*in press*). Optimization of Cervical and Ocular Vestibular Evoked Myogenic Potential Testing Using an Impulse Hammer in Adults, Adolescents, and Children. *Otol Neurotol*.
- Chihara Y, Iwasaki S, Ushio M et al. Vestibular-evoked extraocular potentials by air-conducted sound: another clinical test for vestibular function. Clin Neurophysiol 2007;118:2745-2751.
- Halmagyi GM, Curthoys IS. A clinical sign of canal paresis. Arch Neurol 1988;45:737-739.
- MacDougall HG, Weber KP, McGarvie LA et al. The video head impulse test: diagnostic accuracy in peripheral vestibulopathy. Neurology 2009;73:1134-1141.
- McGarvie LA, MacDougall HG, Halmagyi GM et al. The Video Head Impulse Test (vHIT) of Semicircular Canal Function - Age-Dependent Normative Values of VOR Gain in Healthy Subjects. Front Neurol 2015;6:154.
- Hamilton SS, Zhou G, Brodsky JR. Video head impulse testing (VHIT) in the pediatric population. Int J Pediatr Otorhinolaryngol 2015;79:1283-1287.
- **Janky, KL**, Patterson, JN, Shepard, NT, Thomas, MLA, Barin, K, Cruetz, T, Schmid, K, Honaker, JA (2018). Video head impulse test (vHIT): The role of corrective saccades in identifying patients with vestibular loss. *Otol Neurotol 39*(4):467-473.

References

- Lehnen N, Ramaioli C, Todd N et al. Clinical and video head impulses: a simple bedside test in children. Journal of Neurology 2017;264:1002-1004.
- Ross LM, Helminski JO. Test-retest and Interrater Reliability of the Video Head Impulse Test in the Pediatric Population. Otol Neurotol 2016;37:558-563.
- Wiener-Vacher SR, Wiener SI. Video Head Impulse Tests with a Remote Camera System: Normative Values of Semicircular Canal Vestibulo-Ocular Reflex Gain in Infants and Children. Front Neurol 2017;8:434.
- Davalos-Bichara M, Agrawal Y. Normative results of healthy older adults on standard clinical vestibular tests. Otol Neurotol 2014;35:297-300.
- Matino-Soler E, Esteller-More E, Martin-Sanchez JC et al. Normative data on angular vestibulo-ocular responses in the yaw axis measured using the video head impulse test. Otol Neurotol 2015;36:466-471.
- Hulse R, Hormann K, Servais JJ et al. Clinical experience with video Head Impulse Test in children. Int J Pediatr Otorhinolaryngol 2015;79:1288-1293.
- Mantokoudis G, Saber Tehrani AS, Kattah JC et al. Quantifying the vestibulo-ocular reflex with video-oculography: nature and frequency of artifacts. Audiol Neurootol 2015;20:39-50.

References

- Charpiot A, Tringali S, Ionescu E et al. Vestibulo-ocular reflex and balance maturation in healthy children aged from six to twelve years. Audiol Neurootol 2010;15:203-210.
- Chan FM, Galatioto J, Amato M et al. Normative data for rotational chair stratified by age. Laryngoscope 2016;126:460-463.
- Casselbrant ML, Mandel EM, Sparto PJ et al. Longitudinal posturography and rotational testing in children three to nine years of age: normative data. Otolaryngol Head Neck Surg 2010;142:708-714.
- Staller SJ, Goin DW, Hildebrandt M. Pediatric vestibular evaluation with harmonic acceleration. Otolaryngol Head Neck Surg 1986;95:471-476.
- Eviatar L, Eviatar A. The normal nystagmic response of infants to caloric and perrotatory stimulation. Laryngoscope 1979;89:1036-1045.
- Casselbrant ML, Furman JM, Mandel EM et al. Past history of otitis media and balance in four-year-old children. Laryngoscope 2000;110:773-778.
- JONGKEES LB, MAAS JP, PHILIPSZOON AJ. Clinical nystagmography. A detailed study of electro-nystagmography in 341 patients with vertigo. Pract Otorhinolaryngol (Basel) 1962;24:65-93.

References

- Andrieu-Guitrancourt J, Peron JMDD, Aubet JCP. Normal Vestibular Responses to Air Caloric Tests in Children. International Journal of Pediatric Otorhinolaryngology 1981;245-250.
- McCaslin DL, Jacobson GP, Bennett ML et al. Predictive properties of the video head impulse test: measures of caloric symmetry and self-report dizziness handicap. Ear Hear 2014;35:e185-e191.
- Brookhouser PE, Cyr DG, Peters JE et al. Correlates of vestibular evaluation results during the first year of life. Laryngoscope 1991;101:687-694.
- Christy JB, Payne J, Azuero A et al. Reliability and diagnostic accuracy of clinical tests of vestibular function for children. Pediatr Phys Ther 2014;26:180-189.
- Oyewumi M, Wolter NE, Heon E et al. Using Balance Function to Screen for Vestibular Impairment in Children With Sensorineural Hearing Loss and Cochlear Implants. Otol Neurotol 2016;37:926-932.
- Janky K, Thomas M, High R et al. Predictive factors for vestibular loss in children with hearing loss. American Journal of Audiology *in press*.

References

- McCaslin DL, Jacobson GP, Lambert W et al. The development of the vanderbilt pediatric dizziness handicap inventory for patient caregivers (DHI-PC). Int J Pediatr Otorhinolaryngol 2015;79:1662-1666.
- Pavlou M, Whitney S, Alkathiry AA et al. The Pediatric Vestibular Symptom Questionnaire: A Validation Study. J Pediatr 2016;168:171-177.
- Pavlou M, Whitney SL, Alkathiry AA et al. Visually Induced Dizziness in Children and Validation of the Pediatric Visually Induced Dizziness Questionnaire. Front Neurol 2017;8:656.