2020

Comparing Parent-report and Performance-based Measures of Vestibular Processing

Elisha D. Chambers
Virginia Commonwealth University

Comparing Parent-report and Performance-based Measures of Vestibular Processing

A dissertation submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy at Virginia Commonwealth University

By

Elisha D. Chambers
Masters of Science, Howard University, 2011
Bachelor's of Science, University of Maryland, 2009

Advisor: Stacey Reynolds, Associate Professor
Department of Occupational Therapy
College of Health Professions

Virginia Commonwealth University
Richmond, Virginia
October, 2020

Table of Contents

Introduction *1*

The Vestibular System and Motor Development **1**

Overview of Vestibular Dysfunction **2**

Vestibular based motor disorders 3

Vestibular based discrimination disorders 3

Childhood disorders commonly associated with vestibular dysfunction 3

Assessment Approaches **4**

Performance-based measures. 4

Parent-report measures 5

Problem Statement **5**

Study Objectives **6**

Research questions **6**

Summary **7**

Literature Review *9*

Anatomy and Physiology of the Vestibular System **9**

Vestibular nuclei 11

Vestibular and cerebellar connections 11

Ascending vestibular pathways 12

Descending vestibular pathways 13

The Vestibular System and Related Terms **14**

Balance 14

Postural control 14

Postural sway 15

Nystagmus. 15

Proprioception. 16

Somatosensation 16

The Vestibular System in Typical Development 17

Birth-one year. 17

Early childhood. 18

Age 10 to maturation 19

Signs of Vestibular Dysfunction 20

Ayres' Sensory Integration Theory 21

Praxis. 24

Sensory Integration in Clinical Practice Today 24

A new nosology. 25

Measurement of sensory processing and integration. 27

Identifying and Assessing Vestibular Dysfunction in Occupational Therapy. 28

Performance-based measures. 29

Parent or teacher-report measures. 32

Limitations of assessment methodologies. 33

Correlating Parent–Report and Performance-Based Measures of Vestibular Function. 34

Summary and Conclusion 37

Methods 39

Research Design 39

Sample. 40

Procedures. 41

Study Measures 42

Sensory Processing Measure. 43

Missing data 44

Psychometric Properties. 44

Bruininks Oseretsky Test of Motor Proficiency- Second Edition. 45

SWAY Balance application. 46

Post-rotary nystagmus 47

Data Analysis **48**

Data collection and cleaning 52

Results ***54***

Sample Characteristics **54**

Preparing Data for Analysis **55**

Results Related to the First Specific Aim (RQ 1-2, see Table 1) **56**

Results Related to the Second Specific Aim (RQ 3, see Table 1) **60**

Discussion ***63***

Discussion Related to the First Specific Aim **63**

Cutoff levels. 64

Discussion Related to the Second Specific Aim **65**

Discussion Related to the Third Specific Aim **66**

The SPM and the BOT-2 66

The SPM and PRN. 67

The SPM and SWAY Balance application 67

Limitations 68

Conclusion 69

References ***72***

Appendix A ***79***

Appendix B*... *80

Vita*.. *83

List of Tables

Table 1. Statistical Procedures and Research Questions 50

Table 2. Demographic Characteristics of Participants Classified as

Functional vs. Dysfunctional 55

Table 3. Collinearity Diagnostic Table 56

Table 4. Unadjusted Logistic Regressions of Parent-report data and Direct Measures............57

Table 5. Correlations Between Parent-report and Direct Measures 61

List of Figures

Figure 1. Miller et al.'s 2007 Proposed Nosology of Sensory Processing Disorder 2

Figure 2 Vestibular Apparati 9

Figure 3. Bundy's Model of Disordered Sensory Integration 21

Figure 4. Taylor & Trott's Pyramid of Learning 25

Figure 5. Study Measure Flowchart..42

Figure 6. ROC Curve Analysis of Parent-report subtest scores and Direct Measures.............59

Acknowledgement

There are so many people and organizations that made my project possible. First, I would like to thank my amazing committee, led by Dr. Stacey Reynolds. I am so thankful for her patience, expertise, and for making the time in her busy schedule to devote to this project. I am grateful for the opportunity to have learned from Dr. Reynolds who is an exemplar of the researcher that I would like to become. I am also very thankful to Dr. Adam Sima who provided guidance on the statistical procedures used in this project. I am so grateful for the direction and guidance from Dr. Christopher Zalewski. I would not have guessed that we would share similar research interests nearly 11 years after being his student. Dr. Zalewski has been an amazing resource and support. I look forward to sharing my excitement about the vestibular system with my students, just like you did for me. I am also very grateful to Dr. Carol Ivey and Dr. Laurie Cathers who gave their time to this project and provided timely feedback. I also want to express how thankful I am for all of the families that signed their children up to participate in my study.

I am thankful for my grandmother and encouraging friends for their prayers throughout this program. It has been a very long journey, with many setbacks. Their support and prayers have helped me persevere until the end. I also want to thank my church family, especially Elder Crosby, for taking a personal interest in me and my success in this program.

I want to express how deeply appreciative I am for the professors at Howard University who have kept in touch with me and provided support throughout my studies. I am especially grateful for Dr. Sylvia Anderson, who took the time to counsel me on the difference between an OTD and Ph.D and for encouraging me to excel. I am very thankful to have amazing colleagues, friends, and mentors in Dr. Frederick Covington and LaTanya Henriquez, who helped me recruit subjects for the study. Finally, I want to express my gratitude for the support that I received from my employer KIPP DC Public Charter School. Their respect for research and their support for my project and professional development is greatly appreciated.

Abstract

Comparing Parent-report and Performance-based Measures of Vestibular Processing

By Elisha Chambers, MS. OTR/L

A dissertation submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy at Virginia Commonwealth University

Virginia Commonwealth University, 2020

Major Director: Stacey Reynolds, Ph.D OTR/L
Associate Professor, Department of Occupational Therapy

In the field of occupational therapy, there is a need to explore the relationship between performance based-measures and parent-report measures of vestibular functioning because thorough assessment sets the foundation for effective intervention. Time constraints, child distractibility, and limited participation are all issues that pediatric occupational therapists face during evaluations. It is important for clinicians to streamline the evaluation process, determining which assessments are most likely to yield the most valuable information in the time allowed. Assessing the relationship between assessment methods has the potential to uncover possible redundancies in the evaluation process. If there is a strong predictive relationship between parent responses and performance-based measures, clinicians may conclude that performance-based measures and parent-report measures are measuring the same or very similar aspects of vestibular processing and opt to only administer parent questionnaires, which require less time and equipment. If there is little correlation between assessment methods, clinicians may conclude that the assessments are measuring different aspects of vestibular processing and justify administering both types. Moreover, a better understanding of how parent-report measures and performance-based measures relate to one another will also inform clinicians about what information can, and should, be inferred from test results and, equally as important, what inferences cannot, or should not, be made.

We hypothesized that the information collected from the Sensory Processing Measure could be used to predict the child's performance on at least one of the performance-based measures of vestibular

function. We found a meaningful relationship between the Balance and Motion T-score on the SPM and the child's performance on the Balance subtest of the Bruininks Osteretsky Test of Motor Proficiency-2nd Ed. The BAL T-score was determined to be a *fairly* useful predictor of the child's performance on the Balance subtest of the BOT-2 while the Body Awareness T-score was found not to be a useful predictor of the child's objective performance on the BOT-2 or any of the direct measures of vestibular function. Furthermore, we found that the SPM's T-score cutoff of 60 had an accuracy of 73.3% in identifying those with a vestibular disorder, which was close to our targeted 80%. Next, after entering in all the parent-report data and performance-based data into an adjusted model, the SWAY Balance variable was found to be the only assessment related to predicting the child's performance on the Balance subtest of the BOT-2. Lastly, in the exploratory analysis we found that, there were *moderate* correlations seen at the subtest and item level when examining the relationship between parent responses on the BAL subtest and the performance-based measures and *moderate* to *large* correlations observed between item level parent responses on the BOD subtest and the performance-based measures. The findings of this study support the relationship between parent reporting and their child's performance on objective measures, more specifically technology-assisted measures. Further research is needed to explore the role that technology-assisted assessment of sensory processing has in quantifying baseline sensory processing skills and tracking the response to intervention overtime.

Chapter I

Introduction

Pediatric occupational therapists (OTs) are responsible for effectively evaluating and treating children with disabilities. Intervention focuses on improving the child's functional performance in the home, school, and play environments. OTs trained in the Sensory Integrative (SI) framework aim to decrease barriers to participation in daily living tasks through engaging children in meaningful sensory activities. Providing vestibular input is often a major part of SI treatment because the vestibular system acts as an anchor to human performance. Since proper vestibular functioning sets the foundation for successful participation in many daily living tasks, assessing the vestibular system is an integral part of occupational therapy evaluations. Occupational therapists use a variety of assessment approaches including direct measures of the child's performance and indirect measures using proxy parent reporting. Both methods are used today and provide unique information respectively. Yet before intervention and assessment, it is first important to understand how typical vestibular function supports daily life skills and how the manifestation of dysfunctional vestibular processing impairs these skills.

The Vestibular System and Motor Development

The vestibular system's most basic functions are processing movement and maintaining balance. Vestibular input modulates ocular reflexes needed for gaze stability, as well as helps with the coordinated movement of limbs, and muscle activation required for adequate postural control (Cullen, 2012; Rine & Wiener-Vacher, 2013). The proprioceptive and vestibular systems work closely together in maintaining balance; so much so, that clinically, it can be difficult to separate the contributions of each system. This paper primarily focuses on the vestibular system (as it is most commonly referred to as the system responsible for balance) and exploring the relationship between differing modes of assessment.

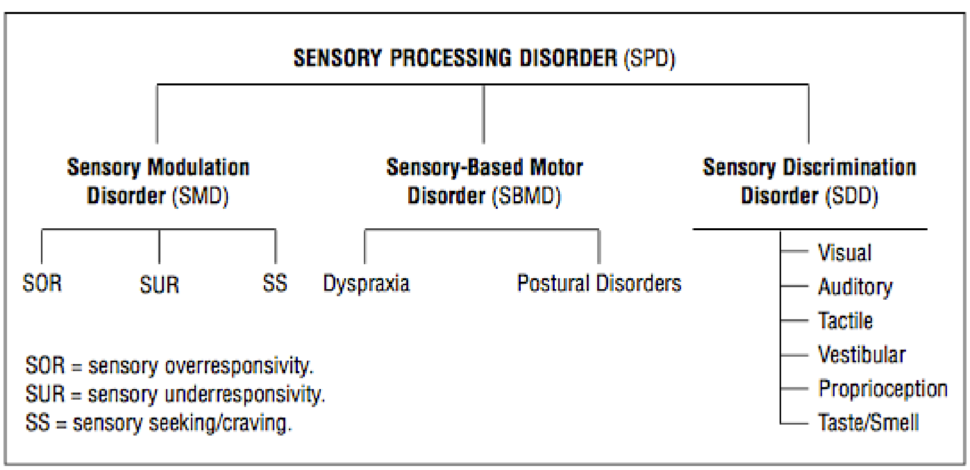
Functional postural control and balance promote healthy child development and are needed for the successful participation in various learning and play activities (Rine & Wiener-Vacher, 2013; Jirikowic, et al., 2013). The vestibular system is anatomically and functionally connected to a variety of different sensory and motor systems. As such, vestibular dysfunction can have a diffuse impact on one's global functioning, impair one's academic performance and impact childhood occupations such as playing sports (Said, Ahmed &Mohammed, 2015).

Overview of Vestibular Dysfunction

Vestibular dysfunction can co-occur in children with sensory processing disorders and/or other medical and learning disorders, which is why a SI approach is commonly used in pediatric occupational therapy settings. According to Miller and her colleagues, there are three subtypes of sensory processing disorder (SPD): sensory modulation disorders (SMD), sensory-based motor disorders (SBMD), and sensory discrimination disorders (SDD) (Miller, Anzalone, Lane, Cermak, & Osten, 2007). Ahn and colleagues (2004) found that 13.7% of the parents of current kindergarteners surveyed in their study reported signs and symptoms consistent with a SPD diagnosis and conservatively estimated that approximately 5% of incoming kindergarteners would meet the criteria of a SPD. While not all children with SPD have a vestibular component to the disorder, vestibular dysfunction can occur within all three SPD subtypes. Figure 1 is an overview of Miller et al.'s proposed SPD nosology.

Figure 1

Miller et al.'s Proposed Nosology of Sensory Processing Disorder



Vestibular based modulation disorder. Children with sensory modulation disorders may over-respond to vestibular input and be very cautious, under-respond and appear not to register movement, or intensely seek out sensory input and take movement risks such as jumping from heights with little regard for safety. Ben-Sasson and colleagues (2009) reported that 16.5% of children age seven to eleven had some symptoms of sensory over-responsivity, though diagnostic levels were not assessed.

Vestibular based motor disorders. There are two subtypes of sensory-based motor disorders and dysfunctional vestibular processing is believed to contribute to both. Children with SBMD can have dyspraxia and experience considerable difficulty learning new motor skills such as jumping jacks and/or how to pump a swing. Children with a SBMD may also have a postural disorder and have difficulty navigating uneven surfaces and/or maintaining an erect seated posture (Miller et al., 2007).

Vestibular based discrimination disorders. Children with sensory discrimination disorders tend to have problems discerning different stimuli (Miller et al., 2007). For example, a child with vestibular discrimination challenges may feel that they are moving when in a stationary car due to difficulty separating moving visual input from self-motion. Normally the optokinetic and vestibular reflexes integrate to generate eye movements that exactly offset head movement, yet when there is a mismatch, it inaccurately produces the sensation of self-motion (Canalis & Lambert, 2000).

Childhood disorders commonly associated with vestibular dysfunction. There is evidence that children with Autism Spectrum Disorder (ASD), experience vestibular differences that lead to impaired postural control and stereotypical behaviors, such as rocking and bouncing in place, which restrict their attention and participation in daily routines and play actives (Reinert, Jackson & Bigelow, 2015). Children with Fetal Alcohol disorder are known to have balance deficits which limit their participation in play tasks, learning activities, and can lead to disruptive behaviors (Jirikowic et al., 2013). Their early exposure to alcohol is thought to lead to poor central processing of vestibular input and interfere with its efficient use in planning motor actions (Jirikowic et al., 2013). Children with frequent otitis media (ear infections) can also experience balance disturbances. Some researchers argue that otitis media with effusion (i.e., an ear infection with a buildup of fluid in the middle ear) is the chief cause of vestibular dysfunction in children (Said et al., 2015). Studies have found that, in some children with otitis media with effusion, vestibular function remains impaired even after the child receives treatment and the ear infection clears (Said et al., 2015). Vestibular dysfunction is also common among children with Developmental Coordination Disorder and learning disabilities such as dyslexia (Pienaar, Botha, Vermeulen, & Ballack, 2007).

Assessment Approaches

In occupational therapy, appropriate goal setting and interventions for children with SPD and other conditions impacting vestibular processing are based on reliable assessments and their correct interpretation. Currently there are few standardized measures of vestibular function for use in children that can be easily administered by occupational therapists in clinical settings (Mulligan, 2011). The assessments that are available can be divided into direct measures of the child's performance during structured tasks, and indirect measures which are based on proxy parent reports of the child's behavior (Chu, 2016; Nandi & Luxon, 2008; Mulligan, 2011). Indirect measures are often in the form of parent-report questionnaires. Both types of assessments can be used to help clinicians draw conclusions about the impact of vestibular dysfunction on functional performance.

Performance-based measures. Performance-based measures such as the *Bayley Motor Development Scale- Third Edition* (Bayley, 2006) and the *Bruininks Oseretsky Test of Motor Proficiency-Second Edition* (BOT-2; Bruininks & Bruininks, 2005), used in clinics often look at the component skills that are believed to support functional participation in daily tasks. For example, the BOT-2 assesses a child's balance by identifying skill deficits that may impact childhood occupations such as safely navigating one's school or home environment. Since the vestibular system mediates balance reactions, a therapist can infer links between vestibular function and participation through the use of this assessment tool. Though performance-based measures used by pediatric occupational therapists do not explicitly measure neurological vestibular processing, they are favored because they yield objective findings that are linked to participation and improvements can be easily measured and tracked over time. Objective data is important to families, insurance companies, and other funding agencies who are interested in monitoring progress.

Parent-report measures. In the clinic setting, parent-report questionnaires of sensory functioning are often used to supplement performance-based measures because they provide insight into trends in the child's use of sensory input in their natural environments (Johnson-Ecker & Parham, 2000; Lalor, Brown, & Murdolo, 2016). Questionnaires are useful because they take into account a wider span of time and provide useful information that can sometimes be overlooked by performance-based measures (Kennedy et al., 2012). For example, many questionnaires ask the parent to reflect on trends in their child's performance over the last month or several months as well as in the home and in community settings (e.g., eating out at a restaurant). Furthermore, in settings such as school, conducting performance-based measures may not always be feasible due to time or space restrictions. In these settings, parent-report questionnaires may be one way to acquire information about a child's sensory processing. Despite the convenience of their use, parent-report measures are thought to be inadequate standalone measures of vestibular function because they are proxy reports, not objective measures, of the child's functioning. Additionally, according to Nandi and Luxon (2008), parent responses are often influenced by the parent's own experiences. Therefore, their answers may not be an accurate reflection of their child's abilities. To date, very few studies have investigated whether parent-report questionnaires designed to measure vestibular functioning accurately reflect their child's ability to perform vestibular-based functional tasks.

Problem Statement

In the field of occupational therapy, there is a need to explore the relationship between performance based-measures and parent-report measures of vestibular functioning because thorough assessment sets the foundation for effective intervention. Time constraints, child distractibility, and limited participation are all issues that pediatric OTs face during evaluations. It is important for clinicians to streamline the evaluation process, determining which assessments are most likely to yield the most valuable information in the time allowed. Assessing the relationship between assessment methods has the potential to uncover possible redundancies in the evaluation process. If there is a strong predictive relationship between parent responses and performance-based measures, clinicians may conclude that performance-based measures and parent-report measures are measuring the same or very similar aspects of vestibular processing and opt to only administer parent questionnaires, which require less time and equipment. If there is little correlation between assessment methods, clinicians may conclude that the assessments are measuring different aspects of vestibular processing and justify administering both types. Moreover, a better understanding of how parent-report measures and performance-based measures relate to one another will also inform clinicians about what information can, and should, be inferred from test results and, equally as important, what inferences cannot, or should not, be made.

Study Objectives

This study sought to explore and improve the understanding of the different approaches that OTs use to assess vestibular function. To date it is unclear how direct measures relate to indirect measures of vestibular function. A better understanding of this relationship will help clinicians and researchers know if both modes are necessary to accurately capture the functioning of this system. If parent-report measures show a strong correlation to direct measures, this finding may reduce evaluation time and streamline the process. High correlations between modes of testing would validate the inferences currently being made in the field concerning sensory functioning as the basis of motor development and learning. The objective of the study was to examine the relationship between the child's performance on direct measures of vestibular function and indirect measures of vestibular function. The following research questions and hypotheses have been identified.

Research questions.

1. Are parent perceptions of their child's vestibular function, as measured by the Sensory Processing Measure (SPM) predictors of the child's objective performance?

   $H_0$1: The SPM is not a predictor the child's actual use of vestibular input, as measured by the BOT-2, SWAY mobile application, and duration of post-rotary nystagmus.

   $H_1$1: The SPM is a predictor of at least one performance-based measure of vestibular function
2. What cutoff ranges on the SPM best discriminate functional vs. dysfunctional performance?
3. Which parent response items, and measures best discriminate functional vs. dysfunctional vestibular processing as measured by the BOT-2?

4. Is there a relationship between the parent's item-level responses on the SPM and performance-based measures of vestibular function?

$H_0$4: There is no relationship between the results of performance-based measures and parent-report measures of vestibular processing.

$H_1$4: A relationship will be found between at least one performance-based indicator of vestibular function and parent-reports of vestibular function.

To test the above hypotheses, children with identified and/or suspected vestibular processing disorders completed a three-part battery of performance-based assessments (BOT-2, The mCTSIB protocol of the SWAY application, and measurements of the duration of their post-rotary nystagmus following clock-wise rotation and counter-clockwise rotation). The child's parent completed the Sensory Processing Measure-Home Form (SPM; Parham, 2007). Data analysis looked at the relationships and predictive capacities of the assessments using separate logistic regressions. More specifically, analysis occurred in the following three tiers. First, to answer the primary aim of the study, logistic regressions were used to determine the likelihood that the child will perform outside/ below the average range on the performance-based measures, using parent responses as predictors. SPM subtest responses served as predictors and the performance-based measures served as dependent variables. Second, a receiver operating characteristic (ROC) curve analysis was used to examine how the predicted probabilities, generated from the logistic regression, compared to child's actual performance (i.e., examine the true positive versus false positive rate). The third and final level of analysis was an exploratory analysis of correlations between the individual SPM item responses and various performance-based measures.

Summary

In summary, the vestibular system is a complex system that supports a number of skills needed for successful participation in daily tasks. It is important for clinicians and researchers to use the most appropriate measures and means of assessment to adequately capture the child's current functional (dis)abilities and then be able to develop the most effective course of treatment. Understanding how certain measures are associated will help clinicians determine which of the available tools are most sensitive to detecting vestibular dysfunction, as well as determine how the information collected from various assessment methods can be utilized most efficiently in occupational therapy practice settings.

Chapter II

Literature Review

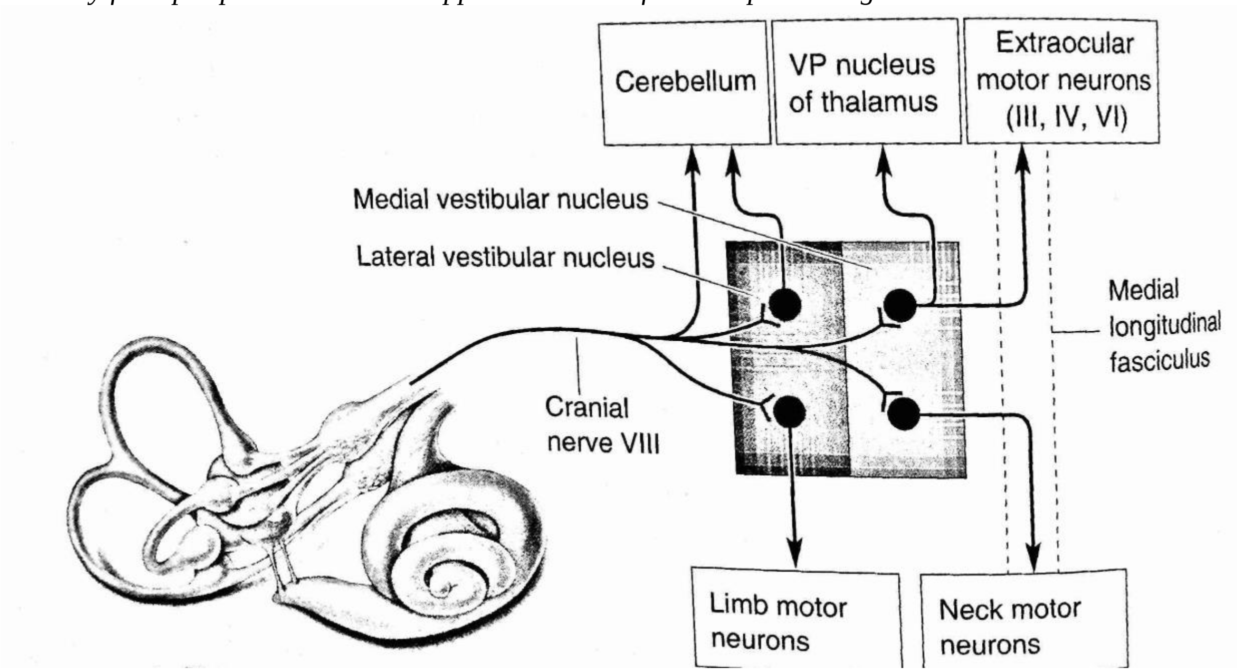
This chapter covers the neuroanatomy and physiology of the vestibular system and the theory of sensory integration that were used to guide concepts and constructs in this project. Literature was reviewed related to the measurement of vestibular functioning in children and gaps in this literature base was identified.

Anatomy and Physiology of the Vestibular System

The vestibular system in comprised of peripheral nervous system structures and central nervous system (CNS) structures and pathways (Figure 2). The peripheral portion of the system contains the sensory receptors. The vestibular labyrinth, located in the inner ear, encompasses three fluid filled semicircular canals, and two otolith organs (i.e., the utricle and saccule) (Rine & Wiener-Vacher, 2013). Both of these sensory end-organs detect changes in head position. They are located within the membranous labyrinth and respond to the movement of endolymph contained inside. The semicircular canals are positioned in different planes to register movement in each corresponding direction. They respond to angular rotation, or more precisely angular *acceleration*, and *deceleration* (Gutman, 2008; Rine & Wiener-Vacher, 2013). The utricle and saccule respond to linear acceleration and gravity (Gutman, 2008; Rine & Wiener-Vacher, 2013). The vestibular nerve has superior and inferior branches, which, together, carry information from both otolith organs and all three semi-circular canals. In healthy individuals, these sensory organs work together to register input (head movement), and the vestibular branches of cranial nerve VIII carry the input to the central nervous system.

Figure 2

Pathway from peripheral vestibular apparati to sites of central processing



Note: Reprinted with permission from Neuroscience: Exploring the Brian 4th Edition (Bear, Connors & Paradiso, 2016)

The central portion of the vestibular system includes brainstem nuclei, portions of the cerebellum, a network of cortical sites, tracks composed of ascending and descending fibers, and a large network of commissural fibers between the brainstem nuclei. First order afferents from semicircular canals and the otoliths combine in the vestibular portion of cranial nerve VIII. The vestibular nerve splits in two unequal bundles as it approaches the brainstem. The thicker bundle enters the medulla and terminates on one of four vestibular nuclei (often referred to as the vestibular nuclear complex). The thinner bundle travels ipsilaterally to the cerebellum, to terminate in a specific region called the uvula nodulus (Barmack & Yahnitsa, 2013). Second order afferents originating from the vestibular nuclear complex also travel to the cerebellum, as well as other locations within the CNS including the opposing contralateral vestibular nuclear complex, brainstem oculomotor nuclei, the spinal cord, and regions of the cerebral cortex. These connections are described in the following section.

Vestibular nuclei. The vestibular nuclei, located in the medulla, are considered by many as the primary processors of vestibular input (Rine & Wiener-Vacher, 2013). The four vestibular nuclei are located ventral and slightly inferior to the fourth ventricle, and are organized in two columns that extend from the caudal aspect of the pons and throughout the medulla (Kahn & Chang, 2013). Most information from the vestibular nerve synapse first on the vestibular nuclei before ascending or descending to other regions of the CNS. Researchers have now discovered there are different types of neurons found in the vestibular nuclei (Cullen, 2012). Two main categories include those that connect to the visual system and those that connect to postural control mechanisms. The postural control neurons can be thought of as "vestibular-only" neurons (VO)(Cullen, 2012). These neurons could be considered the unimodal branch of vestibular processing as they receive information from the vestibular nerve, send projections to the spinal cord, and are believed to mediate vestibular spinal reflexes. Neurons that interface with the visual system and are referred to as vestibulo-occular reflex (VOR) neurons because they project to oculomotor structures (Cullen, 2012). The VO neurons actively respond during passive head motions while different and distinct neurons interface with the visual system and respond during dynamic active gaze (Cullen, 2012). The differences in neuronal activation help the body discriminate passive whole-body movement produced from externally applied movement activities, such as riding in a car, from active self-motion such as turning your head to look the other direction.

Vestibular and cerebellar connections. The vestibular system projects into the cerebellum via primary and secondary nerve fibers (Barmack & Yahnitsa, 2013). As described previously, the majority of vestibular afferents travel first to the vestibular nuclear complex while some go directly to the cerebellum (Bear, Connors, & Paradiso,2015); the cerebellum also receives vestibular input that has already been processed within the vestibular nuclear complex. The vestibular nuclear complex and the cerebellum work collaboratively and act as the body's "error correcting device" (Gutman, 2008, p.204). Their combined efforts ensure that the excitatory vestibular inputs and inhibiting cerebellar inputs are well balanced (Ayres, 1979). The cerebellum is a key contributor in postural control as it calibrates muscle activity needed for smoothly coordinated voluntary moments and quick reflexes. The cerebellum's inhibitory influence on muscle firing is a function of the inhibitory interneurons found in its cortex (Broussard, 2013).

Ascending vestibular pathways. Anatomically, vestibular neural impulses travel upward (ascend) to influence cortical motor control and motor planning. Unlike other sensory information, however, the vestibular system does not have a primary cortical target, rather input gets distributed to several regions including portions of the parietal cortex, cingulate cortex, and insula (Dieterich & Brandt, 2015; Gurvich et al., 2013; Mast et al., 2014; Shinder & Taube, 2010). A specific set of structures termed the parieto-insular vestibular cortex (PIVC) has been identified as playing a central role in the cortical vestibular network, with two thirds of the neurons in this region responding to vestibular input (Baloh et al., 2011). Vestibular input is integrated with visual and somatosensory input in other brain regions such as the posterior parietal cortex (Broadmans areas 5 & 7), which then projects to motor planning regions of the frontal lobe (Bear, 2016). It is through these primary and secondary cortical sites that vestibular information is thought to contribute to conscious awareness of body position in space, motor planning, and skilled motor coordination.

Vestibular signals processed in the vestibular nuclear complex also ascend to influence ocular motor control and ocular reflexes. Secondary afferents from three of the four the vestibular nuclei travel within the medial longitudinal fasciculus (MLF) to innervate the motor nuclei of the oculomotor, trochlear, and abducens cranial nerves which are responsible for eye movements (Barmack & Yahnitsa, 2013). This is the general means by which the vestibular system influences steady gaze and visual clarity during head movement. More specifically, it is accomplished through a series of simple reflex arcs referred to collectively as the vestibular ocular reflex (VOR). When one actively turns their head to the right, the fluid in the membranous labyrinth (endolymph) causes a gelatinous deflection of the sensory end organ (known as the cupula) in the semicircular canals in the opposite direction. This in turn causes increased firing of the ipsiversive vestibular nerve, signaling the direction of the head turn. Neural impulses are then sent to the nuclear complex and the cerebellum and then to the brainstem motor nuclei which control eye musculature. The result is contraction of the lateral rectus muscle of the left eye, and contraction of the medial rectus muscle of the right eye, causing the eyes to deviate conjugately to the left (Kahn and Chang, 2013, Cullen, 2012). This deviation of the eyes in the opposite direction, to that of head movement, permits steady visual fixation of a visual target during passive head movements, provided the conjugate eye movement occurs at the same velocity of head movement. This passive ocular reflex defines the basis of the vestibulo-ocular reflex, or the VOR. Much of the research done on vestibular functioning involves examining VOR because it is generally the easiest vestibular component to measure in patients regardless of age. Other vestibular structures are much harder to access (Canalis & Lambert, 2000; Baloh et al., 2011).

Descending vestibular pathways. From the vestibular nuclei, vestibular input is also directed to the spinal cord via complex descending pathways. These pathways are primarily responsible for mediating equilibrium responses, postural reactions, and muscle tone (Canalis & Lambert, 2000). These tracts connect to anterior horn cells of the spinal cord to produce functional extensor tone needed for adequate posture and stance in skeletal muscles (Gutman, 2008; Morlet, 2013). More specifically, the lateral vestibulospinal (LVST) tract and the medial vestibulospinal tract (MVST) are the two major tracts responsible for posture and balance (Canalis & Lambert, 2000). The LVST is the longer tract of the two. It originates primarily from the lateral vestibular nucleus, and travels ipsilaterally to the lumbosacral portion of the spinal cord (Canalis & Lambert, 2000). It aids in the extension of the lower extremities. The MVST primarily extends from the medial vestibular nucleus. It is a shorter descending tract, which travels ipsilaterally to connects with neurons in the cervical region of the spinal cord (Canalis & Lambert, 2000) and helps with head, neck, and shoulder position (Bear et al., 2015).

These descending pathways mediate reflex arcs that quickly respond to changes in one's center of gravity and aid in maintaining balance and/or minimizing injury in the event of falls through mechanisms of protective extension of the arms, legs and neck muscles. The vestibulospinal reflex (VSR) is one such reflex which involves a complex series of tracts that works together with the inhibiting influence of the cerebellum. VSR signals travel on the LVST, MVST and reticulospinal tracts.

The Vestibular System and Related Terms

The vestibular system is a highly researched system that is studied across disciplines. Occupational therapists, audiologists, neurologists, physical therapists, and physicians all examine and/or treat vestibular disorders. Reviewing the literature on the vestibular system, calls for a blending of diverse pools of knowledge and provides exposure to a variety of testing methods. However, results must be interpreted thoughtfully as there is not uniform use of terminology within and between fields. A test may appear to be examining a certain aspect of vestibular processing, yet the test items may indeed be assessing an entirely different construct (Bundy et al., 2002). Furthermore, the lay term *balance* is often used synonymously with vestibular processing; yet they are not the same construct. It is therefore important to establish the following working definitions of these and related terms before discussing how the system is assessed.

Balance. Balance is a general term that describes the mechanism by which one maintains an upright posture and centers their weight within the body's base of support (Guskiewicz, 2011; Patterson, Amick, Thummar, Roger, 2014). Impaired balance is often one of the earliest and most obvious signs of vestibular dysfunction.

Postural control. Postural control is often used synonymously with balance yet there is a difference. Postural control is the integration of input from the visual, vestibular, and somatosensory systems, which activates skeletal muscles in response to one's environment (Jirikowic et al., 2013, Gabriel, 2001). Postural control is a dynamic process that considers (weighs) the reliability of sensory input received from each system in order to enhance postural stability. Postural control and sensory reweighting allows an individual to rely more on visual and vestibular sensory inputs when walking across a sandy beach because the shifting sand under their feet provides variable proprioceptive input to the joints at the ankle, thus reducing their somatosensory input. A person who is overly reliant on a single sensory system to maintain their balance may continue to rely on this sense even when it is inaccurately relaying self-motion information (Bronstein & Pavlou, 2013). Often times children with vestibular dysfunction have difficulty resolving seemingly conflicting sensory information, which leads to falls (Morlet, 2013).

Postural sway. Postural sway is a mechanism by which one maintains postural control. As muscles co-contract around joints to distribute one's body weight within their base of support, there is often observable drifts forward, backward, and, to a lesser extent, laterally to maintain balance. Sway patterns have been studied in the literature. Researchers have found that children use experimental and often ineffective balancing strategies which result in sway patterns that are varied and more oscillatory than adult patterns (Morlet, 2013;Tjernstrom et al., 2007).

Nystagmus. Nystagmus is a term used for the involuntary oscillations ("jerking") of the eyes. It is usually composed of a slower drift of the eyes towards the eccentric ocular orbit (often mediated by the vestibular system), followed by a quick "resetting" of the eyes back in the center primary ocular position (always mediated by a brainstem-cerebellar center, known as the neural integrator). Thus, nystagmus always has a measurable slow and quick phase. There are several types of nystagmus. When nystagmus is present (observed) outside of clinical testing, it is often pathologic. However, nystagmus can often be induced clinically during certain aspects of vestibular assessment. For example, per-phase nystagmus is when the quick phase of the eyes "beat" or "jerk" in the direction of the rotation. Post-rotary nystagmus (PRN) is characterized by the eyes beating in the opposite direction of rotation, once spinning stops. The "beating" of the eyes (i.e., nystagmus) is a response evoked by the vestibular system's natural tendency to move the eyes equal and opposite that of head movements. This reflex is invaluable for animals such as rabbits and other animals of prey, because they have very little spontaneous (voluntary saccadic) eye movement and rely on these reflexes to change the direction of their gaze (Baloh et al., 2011). When the eyes have reached the eccentric range within the ocular orbit, they quickly snap back in the opposite direction; which is a function of the involuntary saccadic system and is often referred to as the fast component (Baloh et al., 2011, Canalis & Lambert, 2000 Morlet, 2013). The average duration of post-rotary nystagmus varies considerably among typically developing children, but has been estimated to be between for 8 -22 seconds (Baloh et al., 2011, Gutman, 2008). An interesting finding is that the magnitude of the nystagmus response depends on one's level of alertness (Canalis & Lambert, 2000; Baloh et al., 2011) due to the vestibular systems connections to the reticular formation which mediates one's arousal. Among OT's, lower duration PRN is believed to be indicative of vestibular dysfunction that manifests itself as challenges with postural control, balance, and motor performance (Mulligan, 2011). PRN lasting longer than expected is also considered vestibular dysfunction and is believed to be associated with an over-responsivity to movement (Mulligan, 2011). A study conducted in 2011 using factor loadings, backed the empirical relationship between low duration PRN scores and lower scores on measures of vestibular and bilateral functioning (Mailloux et al., 2011). An important note to consider when discussing PRN is the considerable effect that visual fixation and testing methods have on skewing this response. Testing nystagmus in a room that has any source of light may allow for some level of visual fixation. Visual fixation can easily suppress or significantly reduce the duration and robustness of this visual reflex. Methods to reduce this threat to validity is discussed in the following chapter.

Proprioception. Proprioception is the awareness of one's body position gained from the feedback from the receptors in muscles and joints. This sense allows one to walk up and down stairs without the visual monitoring of each step. It also helps one grade the amount of force used to interact with objects in their environment. Individuals with sensory integrative and processing disorders who do not effectively process proprioceptive input may struggle to walk on uneven surfaces, have difficulty calibrating force of movements, and generally appear clumsy in their movement (Chu, 2016).

Somatosensation. Carey, Lamp, and Turville (2016) define somatosensory function in general terms as the recognition, discrimination, and registration of bodily sensations. More specifically, somatosensory function is the intersection between all aspects of the tactile system and proprioceptive systems, which contribute to one's body awareness (McLean, Taylor, Blair, Valentine, Carey, Elliot, 2017). Functional somatosensation allows one to identify objects by touch without vision (i.e., stereognosis), understand where their limbs are in space (i.e., kinesthesia), and differentiate between amounts of pressure and different textures (Carey et al., 2016). In their definition, Carey et al. consider tactile discrimination, pressure discrimination, kinesthesia, and proprioception as 'submodalities' of somatosensory function. Because somatosensation supports body awareness, it is often used interchangeably with proprioception in the literature even though it is more of an umbrella term (Gabriel, 2001).

Occupational therapists often examine nystagmus, use balance assessments, as well as indices of postural control and postural sway to determine one's level of functional performance and to uncover areas of dysfunction. While these indices do not test vestibular system pathology, their adequate functioning is dependent on a well-integrated vestibular system. This is key to therapists, especially those using a Sensory Integrative approach, as it gives therapists insight on where to begin intervention in order to enhance the client's occupational performance. With a working understanding of the neuroanatomy and physiology of the vestibular system, along with related terms, the following section will discuss how and why the vestibular system is so important in the normal development of motor skills.

The Vestibular System in Typical Development

Vestibular structures are one of the first systems to develop in utero. At birth, the vestibular apparatus is present and fully functional, yet vestibular responses are poorly calibrated (Nandi & Luxon, 2008; Tjernstrom et al., 2007). As the infant ages vestibular responses are curbed by the cerebellar influences and other emerging central inhibitory contributors (Morlet, 2013). In typically developing children, the vestibular system's maturation follows a predictable sequence to arrive at smoothly coordinated motor outputs. One only reaches this end with adequate perception of vestibular input and its central integration. Vestibular maturation is evidenced in the progression from the jerky and poorly coordinated movements of a newborn's arms and legs to a toddler's improving gait as it learns to walk. As the child ages, its postural control morphs from learning to stand, then walk, and finally run while navigating uneven surfaces and maintaining a steady visual field. Adequate vestibular processing is integral to this entire sequence.

Birth-one year. At birth, the child's movement is dominated by compulsory reflexes that help develop muscle tone and prepare the infant to acquire advanced motor skills. While some natural variation exists, reflexes generally manifest and are integrated in a predictable sequential order. An early indicator of a possible underlying neurological dysfunction is failure of these reflexes to appear and disappear within expected timeframes (Cushing, Levi, & O'reilly, 2013). Once integrated, children then acquire voluntary control and muscle tone in a cephalocaudal manner (Morlet, 2013). A baby learns to protect their airway by lifting and turning their heads. This develops muscle tone in their neck. They develop extensor tone in their trunk, neck, and legs when they are on their stomach and reflexively lift their head, arms, and legs in to extension (airplane position). This prepares them to sit unsupported by the age of approximately six months. Between the ages of six months to one year, the vestibular system becomes better modulated by inhibitory systems such as the cerebellum (Nanadi & Luxon, 2008). The child's movement, which was once dominated by involuntary reflexes, is now purposeful and more smoothly executed. By the time the child is seven to eight months old, the intense drive toward extension is integrated to allow flexion movement patterns to emerge, which pushes the child toward learning to crawl (Ayres, 1979). Some of the earliest symptoms of vestibular dysfunction are delayed crawling, walking, and clumsiness. These early indicators are often overlooked by parents and physicians, mistakenly attributing them to behavioral issues (e.g., refusals to participate being misinterpreted as contrary personality traits, defiant or obstinate behaviors) (Said et al., 2015).

Early childhood. Typically developing children seek out a variety of movement experiences in early childhood, which are believed to help organize and mature the CNS (Gutman, 2008). Typically developing children demonstrate better postural control as they age which opens them up to a wider range of play activities. Tjernstrom et al. (2007) found early movement experiences that place demand on postural control mechanisms also help to refine the child's postural control systems. Their study revealed that before children develop adult-like postural responses they do not exhibit predictable patterns of postural sway, but instead, experiment to find the limits of their balance. Adults on the other hand use predictable patterns of postural sway and switch strategies as the environmental demands change in order to reduce the amount of postural sway (Tjernstrom et al., 2007). An example of a child's experimenting would be a child who is learning to walk across a balance beam or along a curb, first loses his balance nearly every step then, is able to walk hesitantly across with considerable amounts of postural sway righting themselves just before falling off, to finally confidently walking or even running along it with ease. Teachers and caregivers may begin to notice delays in their child's development during early childhood because motor skills can be observed and compared to other children across a variety of contexts. Typically developing preschool aged children and kindergarteners should be able to navigate uneven surfaces such as the playground or a soccer field without falling demonstrating adequate righting and equilibrium reactions. Those with sensory integrative differences, such as vestibular dysfunction, are slow to learn how to appraise sensory input and appear clumsy or avoid typical childhood occupations such as running and jumping. Others may crave intense movement input to the point where it interferes with daily routines and can be unsafe. Both may be signs of vestibular dysfunction (May-Benson & Koomar 2007, Miller et al., 2007).

Age 10 to maturation. The exact age of mature postural responses is not agreed upon in the literature. Nandi & Luxon (2008) state that it is achieved between the ages of 10-14, while other researchers state that it occurs slightly earlier between the ages of seven to nine (Tjernstrom, et al., 2007). Through experience gained over time, adults and adolescences with mature systems are able to automatically select and employ balancing strategies based on environmental demands (Morlet, 2013). It is at this point in development, observable postural sway decreases in variability and magnitude (Morlet, 2013). This maturate response takes place only when the individual is able to consistently reconcile competing sensory input from the visual, vestibular, and somatosensory systems (Morlet, 2013). This information is used effectively when the individual is able to meet daily environmental demands.

The preceding section shows that normal development follows a predictable sequence where a child's movement is first dominated by reflexes, after which they enter an experimental phase where they test the limits of their postural control mechanisms, before finally demonstrating how a mature vestibular-postural reflex system effectively uses and shifts balancing strategies in according to environmental demands. The following section provides an overview of the various manifestations of vestibular dysfunction and which neurological structures are believed to be impacted.

Signs of Vestibular Dysfunction

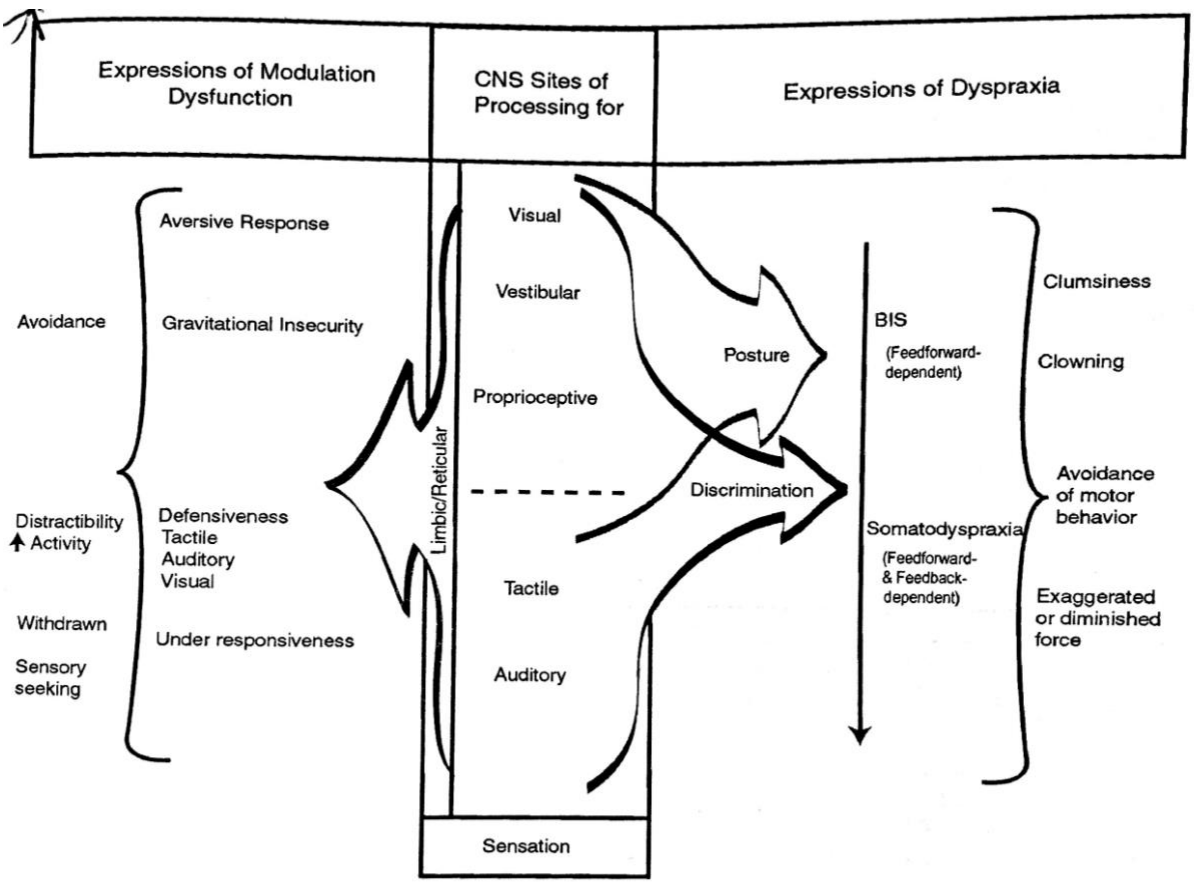
At each stage of development there can be observable signs of vestibular dysfunction in children with sensory integrative and processing difficulties. If these signs and symptoms persist untreated it is unlikely that they will resolve on their own (Niklasson, Niklasson, & Norlander, 2009). These challenges often manifest themselves in school where the child's performance is routinely compared to that of their typically developing classmates. Children who differ in their ability to process and integrate vestibular input often have low endurance, are uncoordinated, or struggle to maintain focus either because they are preoccupied by seeking out added movement opportunities or are focused on avoiding uncomfortable movement input. Children with modulation disorders are often described as risk takers, seeking out intense movement input well past the age that one would typically expect to see this behavior. A school aged child with deficient or delayed equilibrium reactions may frequently fall out of their chair when shifting their weight. Problems effectively relaying and integrating information in vestibular pathways are believed to be the cause of modulation disorders, postural control deficits, difficulties planning and executing novel motor sequences, and/or difficulty discriminating movement input (Miller et al., 2007). Because vestibular dysfunction can manifest in varied, and often opposing, patterns of behavior, theoretical models are needed to help link observable behaviors to their specific subtype based on the nature of underlying sensory dysfunction.

Ayres' Sensory Integration theory helps clinicians, teachers, and parents understand the link between the sensory systems, learning, and motor development. Figure 3 is a model based on Ayres' original work and the advancements in SI theory since then. It shows how one's central nervous system helps to integrate various sensory inputs, disorders that result from dysfunctional sensory integration, and how these disorders manifest behaviorally. This theory provides an evidence-based framework for understanding the functional differences and neurological processes that children with sensory-motor issues have in a clinical context. The following is a discussion of Ayres' Sensory Integration theory.

Included in this discussion is an emphasis on what she believed to be the most influential areas of vestibular functioning that impair motor development and learning.

Figure 3

Disorders resulting from Poor Sensory Integration.



Note: BIS- Bilateral integration and Sequencing disorder. Reprinted with permission from Sensory Integration Theory and Practice 2nd Edition (Bundy, Lane, & Murray, 2002).

Ayres' Sensory Integration Theory

Sensory Integration (SI) theory was developed by Dr. A. Jean Ayres (Ayres, 1979). Much of Ayres' early work on the organization of the CNS has been supported by research today. Ayres grossly divides SI dysfunction into dysfunctions of modulation, and disordered praxis (i.e. dyspraxia). Modulation disorders (depicted on the left side of Figure 3) occur when the child's response to incoming sensory input is either too large or too small. The right side of the model shows the various motor coordination and postural disorders that result from poor sensory processing. Both of these are discussed in further detail in following sections.

In the most basic of terms, “Sensory integration is the organization of sensation for use” (Ayres, 1979, p.5). Ayres often compared the brain to a traffic director or police officer, in that it has the unique responsibilities of attending to and organizing the flood of incoming sensory stimuli experienced during everyday activities (Ayres, 1979). Sensory inputs that are well organized and properly modulated support successful participation in daily living tasks, such as sitting quietly and listening during circle time at school, or having appropriate social exchanges during mealtime conversations at home. Ayres termed the small responses that come together to support participation “adaptive behaviors”. She believed that everyone is born with an immature level of sensory integration, which can improve over time and with experience (Ayres, 1979). Ayres studied how typically developing children progress from reflexive movement patterns, to volitional play tasks that challenge and feed their sensory systems, to a more mature system that integrates multiple sensations to produce complex responses to environmental demands. Ayres posited that one’s ability to integrate sensation occurs on a spectrum that ranges from good to poor. While good sensory integration supports proper function, poor or disordered sensory integration can lead to several noticeable disruptions in certain childhood occupations such as learning and playing. SI theory was originally developed to explain the differences seen in children with learning disabilities (Ayres, 1979). In addition, Ayres worked to identify the role that isolated sensory systems have on functional participation. SI theory highlights the importance of well-integrated sensory systems with a heavy focus on the vestibular, tactile, and proprioceptive systems. The language used in her writings such as *vestibular-proprioceptive system* or *vestibulo-proprioceptive input* acknowledges the naturally interwoven nature of the two systems (Bronstein & Pavlou 2013; Parham & Su, 2014). Her article, “Learning Disabilities and the Vestibular System” published in 1978, emphasized the vestibular system’s link to learning. In this article, Ayres examined the effects that SI therapy (which strongly emphasizes controlled vestibular, tactile, and proprioceptive input) has on children with learning disorders (LD). This pre-test post-test study found that children with a LD and hypo-responsive vestibular systems, evidenced by their shorter than average post-rotary nystagmus (PRN), demonstrated greater academic gains following SI therapy, when compared to a control group of children with LD with hypo-responsive nystagmus, who did not receive the intervention (Ayres, 1978). While the integrative nature of these systems is acknowledged, the information presented in this literature review primarily focuses on the functional manifestations and measurement of the vestibular system.

Modulation. In her writings, Ayres called vestibular receptors "the most sensitive of all sense organs" and comments that their sensitivity is indicative of the importance that this system plays in adaptation (Ayres, 1979, p. 70). Ayres recognized a number of issues that stemmed from vestibular dysfunction and commented, more specifically, that vestibular modulation disorders have a considerable impact on learning and behavior in children (Ayres, 1979).

Ayres organized vestibular modulation disorders into two main categories, vestibular over-reactiveness and under-reactiveness, with several related dysfunctions that fall under these larger categories (Ayres, 1979). At the time Ayres was conducting her research, examining the *duration* of PRN was considered one of the better clinical methods of examining vestibular function and was a large part of how children were identified as over or under-responsive. Ayres referred to children with over-responsive vestibular systems as having an intolerance to movement or as being *gravitationally insecure*. Ayres linked movement intolerance to difficulties processing input from the semi-circular canals. She labeled children gravitationally insecure if they tended to avoid and/or fear movement (Ayres, 1979). Ayres stated that children who are under-responsive to vestibular input tolerate and often seek out excessive amounts of movement, struggle to execute new and familiar tasks, and have difficulty holding anti-gravity positions due to low muscle tone (Ayres, 1979). Through her work testing PRN, Ayres concluded that the duration of the one's nystagmus sheds light on the functionality of the vestibular nuclei and subsequently on how much vestibular input the child is registering. Ayres determined that a PRN that was longer than average indicated an over-responsive system while a PRN that was shorter than average indicated an under-responsive vestibular system (Ayres, 1979). She found that a large number of children with learning and language problems exhibit short duration PRN.

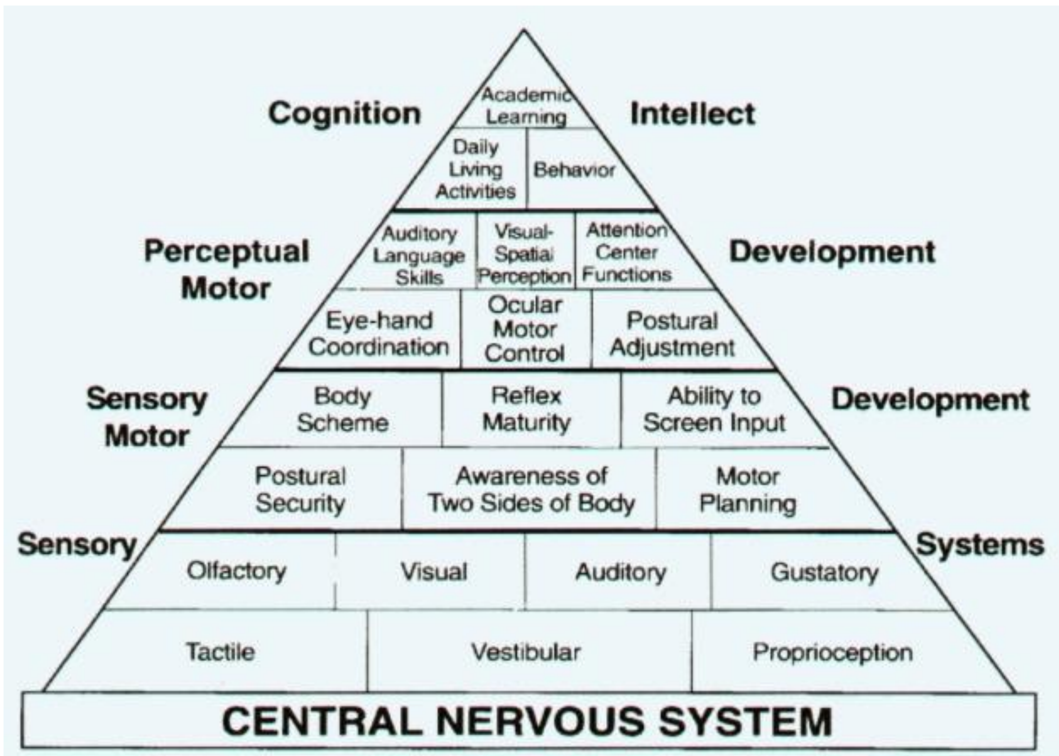
Praxis. Ayres also wrote extensively about children who experienced difficulty motor planning, sequencing, and executing new movement tasks (i.e. dyspraxia). As Figure 3 portrays, Ayres recognized that the vestibular system was one of several sensory systems (e.g., tactile and proprioceptive system) that contributed to these difficulties (Ayres, 1979). Figure 3 depicts two levels of praxis disorders. Postural disorders are those that result from disordered visual, proprioceptive and vestibular input and are termed Bilateral Integration and Sequencing (BIS) disorder. Somatodyspraxia is the second level and is more involved. Both of these disorders can lead to challenges executing complex novel motor sequences (Bodison, 2015). Originally named by Ayres, BIS disorder presents as a constellation of clinical signs including poor performance on measures of bilateral integration, motor accuracy, balance, and shorter than average PRN (Koester et al., 2014). Additionally, tasks involving the coordinated use of one's hands, eyes, and limbs to catch or throw a ball are skills impacted by BIS disorder (Bundy et al., 2002). The link between vestibular processing and praxis is supported by studies that found children exhibiting BIS patterns of dysfunction also tend to exhibit other vestibular signs including poor postural control and low muscle tone (Koester et al., 2014).

Sensory Integration in Clinical Practice Today

Since its inception Ayres' SI theory has continued to develop over time. Based on her own theoretical work, Ayres developed an intervention approach (now trademarked as Ayres Sensory Integration®) that continues to be used clinically. Recent research has supported the use of Ayres Sensory Integration® for improving functional goals in children with differences in sensory processing and integration, including those with Autism Spectrum Disorders (Schaaf, Dumont, Arbesman & May-Benson, 2018). Other clinicians and researchers have applied and expanded Ayres' original theory to develop intervention approaches and treatment models designed for specific populations. Figure 4 depicts one such model from the "How Does Your Engine Run?" Alert Program of Self-Regulation. Designed by occupational therapists Shellenberger and Williams, this model was created to address the need for increased client awareness of their differing levels of arousal, and begin to develop sensory-based strategies to modulate them. It is a useful model because it clearly outlines how success in higher level skill areas is based on a solid sensory foundation. It echoes the strong emphasis that Ayres placed on the vestibular, proprioceptive, and tactile systems, and how these systems support motor planning (i.e., praxis), postural security, bilateral integration, and well-integrated reflexes.

Figure 4

Sensory Integration Theory. Pyramid of Learning



Note: Reprinted with permission (Taylor & Trott, 1991)

A new nosology. Building on the early work of Ayres and information gained thorough empirical studies, Miller and her colleagues (2007) proposed a model to clarify constructs and assist in accurately identifying the various and related sensory processing disorders. Repeating and expanding on many of Ayres' original constructs, the new nosology parses out several vestibular disorders that Ayres originally clumped together. It adds specificity for identification and treatment purposes and classifies three main types of disordered sensory processing as previously discussed in Chapter 1. To summarize, the three main clusters are Sensory Modulation Disorders (SMD), Sensory Based motor disorders (SBMD), and

Sensory Discrimination Disorders (SDD). Vestibular dysfunction can fall under each of the three main types of dysfunction, yet present very differently depending on its subtype. To review, a child with a vestibular modulation disorder who is over-responsive to vestibular input, may demonstrate strong predicable patterns of aversions to swinging too high or too fast, having their head out of an upright and midline position, and/or having their feet off the ground (Miller, Anzalone, Lane, Cermak, & Osten, 2007). A child who is under-responsive to vestibular input may demonstrate delayed head righting when shifted off center and have poor balance. Children who seek out vestibular input may look for intense movement experiences such as climbing and jumping from heights with little regard for their safety.

There are two subtypes of SBMD; the first is a postural disorder and the second is dyspraxia. Those with a postural disorder may struggle due to low muscle tone, have poor postural stability, and may have a delayed labyrinthine righting reflex (Miller et al., 2007). It is believed that children with postural disorders have challenges related to spinal reflexes and their impact on muscles tone, all of which, as discussed earlier, is mediated by the vestibular system. A child with a postural disorder may slouch, use their arms to prop themselves up when seated unsupported on the floor, or use their arms to prop their head when seated in a chair at a table (Miller & Fuller, 2012). Dyspraxia can manifest in different ways including difficulties coming up with ideas on how to interact with items in one's environment (ideation), timing responses, and executing the motor sequence necessary for successful participation. Children with dyspraxia are commonly described as clumsy or uncoordinated and have challenges with motor planning and executing new activities (Bodison, 2015). They generally require more time to learn and master new motor skills when compared to typically developing children. As a result, children with dyspraxia generally avoid movement-based activities, preferring instead to engage in stationary tasks, such as video games and reading (Miller et al., 2007). These types of tasks place little demand on motor coordination and allows the child to have a feeling of success. The two subtypes of dyspraxia commonly co-occur with other sensory modulation and/or discrimination difficulties (Miller et al., 2007). While Ayres has contributed significantly to how occupational therapists understand and treat individuals with SPD, it is important to acknowledge that SI theory and subsequently vestibular dysfunction alone may not be the only factor(s) contributing to observed areas of dysfunction.

A child with a sensory discrimination disorder (SDD) may have difficulty determining the distinct qualities of sensation, such as sharp vs. dull or movement that is fast vs. slow. Functionally, SDD can lead to extra processing time for incoming sensory input leading to slower than average performance (Miller et al., 2007). While many of the same characteristics that Ayres described are found in this new nosology, the discrete types of SPD makes it easier to treatment plan and classify the child's sensory related difficulties.

Sensory Processing Disorder, as conceptualized by both Miller and Ayres, is a complex issue. It can be seen in children with co-occurring diagnoses such as Autism Spectrum Disorder (ASD), Developmental Coordination Disorder (DCD), hearing loss, and Fetal Alcohol Spectrum Disorder (FASD), but can also be a standalone disorder (Allen & Casey, 2017; Carrasco et al., 2014; Jirikowic et al., 2013; Mulligan, 2011). There is no single presentation of SPD which adds another layer of complexity when it comes to studying this population. While there are other neurodegenerative disorders such as muscular dystrophy which can lead to some of the same/similar presenting signs, Ayres was careful in creating as much homogeneity in her samples as possible when conducting her research and in building her theory.

Measurement of sensory processing and integration. Before clinical intervention can take place, it important for clinicians to select an appropriate assessment tool; one that is sensitive and specific enough to identify the areas of sensory processing that are contributing to limited functional participation. Pinpointing the areas of dysfunction that are present are important first steps to effective treatment planning and intervention.

Ayres first assessed vestibular processing and all sensory functioning through a number of clinical observations including PRN and balancing tasks. She later created the Sensory Integration and Praxis Test (SIPT) based on her theory (Goyen, 2011). The SIPT is seen by many in the field of occupational therapy as a comprehensive assessment of sensory processing. It is composed of 17 performance-based subtests including the: Standing/ Walking Balance test, Postural Praxis test, Bilateral Motor Coordination, Postrotary Nystagmus test, Kinesthesia test, and the Sequencing Praxis test. All of the aforementioned tests examine either the combined or isolated (reduced) performance of the vestibular, visual, and proprioceptive systems. Parent-report checklists were included in some of her writings which could then be used to elicit subjective input about the child's functional performance difficulties; questions were comprised of behaviors that characterized sensory specific disorders to help identify the type(s) of sensory dysfunction. Ayres' early work set the stage for advancements in the field and helped to create a template for how to gather information about a child's sensory processing in a clinical setting.

Today, questionnaires, measures of balance, and quantifying nystagmus are still some of the primary modes of examining vestibular function. Advancements in laboratory equipment used outside of the clinic also allows researchers to capture the *velocity* and the *directionally* of PRN and use these as indicators of vestibular physiology. The added specificity of testing instrumentation allows for the identification of the site of lesion in individuals with acute or degenerative vestibular loss. Lab-based measures are generally not well suited for use in pediatric occupational therapy settings as they are not well tolerated by pediatric patients, and are based on neurological frames of reference which do not directly speak to impairments in functional performance; nor do they help identify functional treatment goals. The following is a discussion of how vestibular dysfunction is identified in occupational therapy practice settings using assessment tools that are built on SI principles.

Identifying and Assessing Vestibular Dysfunction in Occupational Therapy. Occupational therapists generally assess and treat vestibular processing and other sensory integrative and processing differences in outpatient clinics. In clinics, therapists typically have access to standardized motor assessments, suspended equipment, balance beams, balance boards, and everyday supplies such as balls, games, and other manipulatives and toys. OTs engage children in play activities during both assessment and treatment to examine functional skills and infer how underlying sensory processes are either supporting, or impeding, the child's performance. Since treatment goals and assessments are driven toward functional skills, OTs are not primarily concerned with determining the site of possible lesions in neural tracts. Instead, clinicians are interested in uncovering areas of occupation that are impacted, identifying which sensory systems are involved, and the performance skills that are lacking or insufficient.

One of the best assessments of functional balance, used in laboratory settings, is the Sensory Organization Test (SOT), which is a primary subtest of Computerized Dynamic Platform Posturography. It is also considered to have a strong vestibular influence because it has been shown to be sensitive to utricle and saccular disorders (Basta et al., 2005). SOT uses sophisticated computer software and large equipment to determine the relative contributions of the visual, vestibular, and somatosensory systems to one's dynamic postural stability. This is accomplished through a complex modification of one's perceptual visual field, a sway-referenced tilting of the platform on which the participants are standing, and elimination of any visual cues to postural stability by having the participants periodically close their eyes during a series of six increasingly difficult postural stance conditions. Though the SOT is a useful tool, it is not a standalone diagnostic measure. Most often, it is part of a larger battery of vestibular and balance assessments. It is typically used by audiologists and physical therapist who have a specialized interest in functional balance assessment and treatment, and only available when the space and funding for such equipment is also available. Furthermore, because of its size SOT is not a practical assessment tool for any setting other than a laboratory.

Fortunately, lab-based measures such as the SOT have been shown to correlate with some performance-based based measures commonly used in clinic, home, and school settings setting (Rine & Wiener-Vacher, 2013). As such, occupational therapists can assess balance functions associated with adequate vestibular processing through various measures in settings where they typically work with children.

Performance-based measures. Performance-based measures of vestibular function are those where a clinician directly observes and rates how a child executes motor sequences and holds balance postures. Performance-based measures often examine a constellation of performance skills believed to support functional participation. Standardized motor assessments such as the Peabody Developmental

Motor Scales (PDMS: Folio & Fewell, 2000), and the Bruininks Oseretsky Test of Motor Proficiency - Second Edition (BOT-2:Bruininks & Bruininks, 2005) assess a child's static and dynamic balance by having children walk on lines, balance on one foot, and/or walk on their tip-toes. Performance conditions on the Balance subtest of the BOT-2 include those where the patient maintains a quiet postural stance with their eyes open, as well as maintaining a quiet postural stance where the patient's eyes are closed in order to examine vestibular-somatosensory processing in the absence of any visual contributions. Other performance-based measures employ strategies such as testing in a dark room or using high magnification lenses to prevent clear visual fixation, thereby reducing visual contributions to balance.

Some performance-based measures have been critiqued for not being functional. Newer assessments such as the *Goal Oriented Assessment of Life Skills* (GOAL: Miller, Oakland & Herzberg, 2013) seeks to address this in its top-down approach. Test items on the GOAL use functional activities such as: sitting and standing while balancing cups of water on a cafeteria tray, and walking a novel path while avoiding obstacles along the way, all while not spilling the water. Similarly, the Miller Function and Participation Scales (M-FUN, Miller, 2006) uses a subtest called the Ball Balance Game, which asks the child to balance a small ball on a spoon. To successfully complete these types of tasks, a child must have adequate postural stability and a well-integrated visual system, be able to quickly shift their gaze from the ball/cups to the path and back again without loss of balance or wandering off course. An inherent limitation of all top-down approaches is the difficulty distinguishing sensory limitations, which are impacting performance from cognitive and/or attentional challenges, which may also be impairing performance.

To supplement the results of standardized motor assessments, therapists will routinely put a child through several clinical observations, such as supine flexion, prone extension, and measures of post-rotary nystagmus. The Clinical Observation of Motor Performance Skills (COMPS; Wilson, Kaplan, Pollock & Law, 2000) is a norm-referenced screening tool that includes many of these clinical observations, along with an item that screens for the retention of primitive reflex patterns, which was noted above as an early indicator of vestibular dysfunction. Therapists can infer links between vestibular function and participation through performance-based of assessment because the vestibular system mediates balance, muscle tone, and postural reflexes. Though performance-based measures used by pediatric occupational therapists do not directly measure neurological vestibular processing, they are favored because they yield objective findings linked to participation, and improvements can be easily measured and tracked over time.

Advancements in technology-based direct measures have also emerged. While not commonly used in clinical practice today, there is a push to move the field in a direction that is evidence-based and cost-effective. Affordable mobile applications such as the SWAY Balance application (SWAY Medical, LLC, Tulsa, OK) is one way to accomplish this. It provides a convenient objective measure of postural sway. The SWAY Balance application takes advantage of the software already housed in mobile devices to measure postural sway under various conditions. This application is being used today in high school and college sports programs to capture baseline measures, and as a tool for ongoing concussion screening. It is well suited for use in therapy settings as well, because it requires only a mobile device and a foam cushion. Research studies using the application have found it to be a valid measure of balance in healthy individuals and those with balance challenges such as concussion (Patterson et al., 2014). Researchers agree that the application has functional use outside of sports related injuries. It correlates well with commonly used measures of balance and can be used by health professionals to objectively measure functional limitations and fall risks (Amick et al., 2015).

Foam cushions are routinely used in clinical settings to assess and treat balance disorders. In treatment, standing on foam cushions encourages the individual to rely on sensory systems other than their somatosensory system (i.e., vison or vestibular) in order to maintain their balance. Standing on a foam cushion during assessments is one way to *reduce* the somatosensory / proprioceptive contributions to balance. Other methods of reducing proprioceptive inputs found in the literature are having subjects stand on movement sensitive platforms, or by disrupting input from legs and ankles using vibrators (Tjernstrom et al., 2007). While somatosensory / proprioceptive contributions can actually never be totally eliminated, they can be reduced or altered. Though these measures reduce somatosensory contributions from the lower leg, they do not fully eliminate proprioceptive contributions because the brain still receives inputs from the pelvic and cervical joints (Hegeman et al., 2007). Instead, these conditions provide insight into how reduced proprioceptive contributions affect posture control (Basta et al., 2005). Reeves and Cermak (2002) state that parsing out proprioceptive input from vestibular input is neither an easy nor necessary step, rather emphasis should be placed on their combined contributions to functional performance, such as maintaining equilibrium and muscle tone. Parham and Su reiterated these findings in their 2014 study designed to explore the discrete nature of sensory systems. They found that while systems such as the tactile, visual, and auditory systems could be considered and treated as separate constructs, the vestibular and proprioceptive systems were tied so closely together that they should be considered a single functional system (Parham & Su, 2014). Unlike proprioceptive input, contributions of one's visual system can be easily isolated from its influence on balance by asking the subject to close their eyes, using high magnification lenses, or testing in a dark room.

Parent or teacher-report measures. Parent or teacher-report questionnaires are useful tools when assessing vestibular functioning in both the school and clinic settings because they are easy to administer, do not require space, and can be completed quickly. In a similar way that Ayres' solicited parent-report information through checklists, Parham and her colleagues (2007) created a 75-item questionnaire called the Sensory Processing Measure (SPM). The SPM has both school and home forms that are completed by the teacher and parent respectively. This measure was designed to be used in conjunction with other clinical observations to identify sensory processing disorders and general features of poor sensory integration (Parham et al., 2007).

The Sensory Profile (SP; Dunn, 2014) is another parent questionnaire that can be used in clinics and school settings. It is based on Dunn's 1997 model of sensory processing. The SP and the SPM have moderate levels of convergent validity ($p=.86$, $p<.01$) (Hansen & Jirikowic, 2013) as they examine some of the same sensory-motor constructs including specific sensory systems such as the vestibular, proprioceptive, and tactile systems and modulation. The SP differs from the SPM because it seeks to uncover patterns in sensory responsivity across sensory systems while the SPM focuses on functioning within and between each sensory system. Both questionnaires are based on an underlying premise that all children exhibit the behaviors described on the questionnaires at some point, yet, it is the *frequency,* with which they are observed, that determines whether the behaviors are impacting functional performance and may be sensory based.

Questionnaires such as the SPM and SP are often used to supplement performance-based measures because they provide insight into how the child uses sensory information in their natural environments (Johnson-Ecker & Parham, 2000; Lalor, Brown, & Murdolo, 2016). Additionally, questionnaires solicit information regarding trends in the child's behavior rather than the "snapshot" information gained from direct observation on a single day (Kennedy et al., 2012).

Limitations of assessment methodologies. In clinical practice today, parent-report information regarding the child's sensory processing is often collected and considered along with the results of direct measures and/or clinical observations. Indirect measures are useful because they provide subjective insight and context that frames the objective scores that clinicians receive from performance-based measures. When used alone, parent reports may miss some nuances of the child's full experience as they are proxy reports, not objective measures of the child's sensory functioning. Additionally, according to Nandi and Luxon (2008), parent responses are often influenced by the parent's own experiences. Therefore, parent responses may not be an accurate reflection of their child's abilities. To date, very few studies have investigated whether parent-report questionnaires designed to measure vestibular functioning accurately reflect their child's ability to perform vestibular-based functional tasks.

Said and colleagues (2015) found that parents often fail to attribute subtle vestibular symptoms, such as clumsiness or difficulty learning to walk, to vestibular dysfunction, particularly in young children. Furthermore, some children with vestibular dysfunction may appear asymptomatic because they are able to use other sensory information to compensate for their dysfunction (Baloh et al., 2011). Direct measures used in clinical settings appear to make up for many of the short comings of parent-report measures in their ability to generate quantitative and objective scores. Performance-based measures are not always practical due to the amount of time and training required to administer, space required to administer, and the need for children completing the testing to be able to attend and follow directions for task completion (Patterson, Amick, Thummar, & Rogerrs, 2014).

The literature shows no strong evidence for the sole use of one method of testing over the other, so it is unclear whether both performance-based measures and parent-report measures need to be administered. From both a research and a clinical standpoint, it would be useful to understand the extent to which these two methods of assessment relate. A better understanding of possible areas of overlap will help identify redundancies in the assessment and help to create a more streamlined process.

Correlating Parent–Report and Performance-Based Measures of Vestibular Function. Few studies have been conducted which examine the concurrent validity of questionnaires and their relationship to assessments that require direct observation (performance-based measures). In 2006, researchers Cattaneo, Regola, and Meotti conducted a study using adult participants with a mean age of 45.3 years to examine the concurrent validity of several commonly used self-report measures of balance, and several other balance assessments requiring direct observation and rating by a clinician. The Berg Balance Scale (BBS) was used in this study. It is commonly used in rehabilitation setting and among older adults. It is a performance-based measure where a clinician rates the individual's performance on various static and dynamic balancing tasks as *Normal* or *Cannot Perform.* The Dizziness Handicap Inventory (DHI) was another measure used in the study. It is a self-report measure that seeks to quantify the adult's perceived level of disability as a result of their impaired vestibular function. This study found a fairly weak correlation (-.32) between the BBS and the DHI. The Activities Specific Balance Confidence (ABC) is another self-report measure used in Cattaneo and colleagues 2006 study. It similarly purports to examine the individual's level of confidence in their ability to perform 16 daily tasks. The researchers found the highest Spearman correlation (-.70) between the two self-report measures; the DHI and ABC. Interestingly, in a separate study, the DHI was found to correlate well with patient's performance-based results from platform posturography (Hanes & McCollum, 2006). The findings of these studies support the assertion that there is some correlation between performance-based measures and indirect measures, yet it calls into question whether clinic-based measures are sensitive enough to capture this relationship and the influence self-reporting versus proxy (parent) reporting.

A study involving child-report data found that responses of typically developing children age 8-12 years old could predict their objective performance on the BOT-2 (a performance-based measure examining strength and agility) (Lalor, Brown, & Murdolo, 2016). This study also found correlations between parent responses on a questionnaire and the child's performance on the composite measure of manual coordination. The children in this study completed the BOT-2 and two self-questionnaires the Physical Self Perception Questionnaire and the Self Perception Profile for Children. The parents completed the Developmental Profile III and the Developmental Coordination Disorder Questionnaire. Regression analysis found that the child's self-report of their performance had the largest number of significant correlations with their physical performance and that the parent proxy responses, though fewer, also yielded useful correlations. This study supports the hypothesis that there is a relationship between questionnaires and performance-based measures of balance function.

Studies using pediatric performance-based assessments and parent-report measures have variable findings. In 2007, White and colleagues compared parent-report responses on the Sensory Profile (SP) to a performance-based measure called the Assessment of Motor Process Skills (AMPS). Sixty-eight children, ages 5-13 years old, were included in this study. The AMPS is a performance-based measure that asks the individual to complete various activities of daily life (ADLs) while the examiner rates the quality of their performance. White et al. found that the strongest relationship between the AMPS and the SP was the vestibular area. They stated that this was an expected finding as the vestibular systems is tied most closely to movement and motor performance. This finding supports the relationship and validity of standardized parent reporting of vestibular function as a proxy to the child's objective performance.

A 2013 study also found links between two questionnaires/checklists, the SPM results and Movement Assessment Battery of Children-2nd Ed. Checklist (MABC-2), and the performance-based counterpart the MABC-2 Balance subtest. In this study, Jirikowic et al. examined the postural control of 10 children ages 8-15.9 years with FASD and 10 typically developing children. The performance portion of the MABC-2 examines three main areas of function including balance, manual dexterity, and ball skills. Researchers found that children in the study group scored 1 SD below that of their typically developing peers on the MABC-2 Balance subtest and that parents of the subjects in the study group congruently reported that their children experienced functional balance difficulties, yet no exact correlational data were reported (Jirikowic et al., 2013).

In a separate study, Said, Ahmed, and Mohamed (2015) tested 80 children age 5 -11 years (50 with known vestibular dysfunction and 30 typically developing children). Researchers used both clinic-based measures (BOT-2 and the Modified Clinical Test of Sensory Interaction in Balance (mCTSIB)) and lab-based vestibular physiology tests (Electronystagmography (ENG) and vestibular evoked myogenic potentials (VEMPs). Before testing, researchers gathered additional information in what they called a "detailed history…taken from all subjects of the control group and study group" (p.153).While the study did not specify whether the history was gathered via child self-reporting or parent proxy reporting, it can be inferred that the parents reported due to the age of the children in the study. Researchers found that 64% of the children in the test group had abnormal ENG findings and concluded that ENG results combined with VEMP test findings appeared to be adequate in detecting vestibular dysfunction. Researchers also found that the BOT-2 and the mCTSIB accurately identified balance abnormalities in young children. The researchers found that there was no relationship between parent perceptions of their child's balance and the child's performance on the BOT-2 Balance subtest or the mCTSIB. Researchers noted they were not surprised by this finding, stating that parents often fail to properly identify vestibular signs and symptoms in their children. Said et al. state that parents attribute difficulties in balance to coordination deficits or troubled behaviors instead of an underlying vestibular deficit (Said et al., 2015). A limitation of this study is, outside of the history taken, no standardized instrument of parent-reporting was used in this study. The finding that there is no relationship between parent perceptions and child performance may be more accurately stated as non-standardized histories lack the sensitivity to detect relationships between parent perceptions and objective child performance. This study echoes findings of other studies which link discorded vestibular functioning to balance and coordination anomalies in children.

Based on the literature to date, there is mixed evidence that a relationship exists between performance-based and parent-report measures of balance functioning. It is also unclear which aspects of vestibular processing tested through questionnaires correlates to one's objective performance. The variability in the literature supports the need for research to uncover the exact relationship between direct- and indirect-measures of vestibular processing. To date, it is unclear whether discrepant findings between studies examining vestibular functioning are due to differences between adult and child reporting, (mis)labels on constructs involved in the study, or low concurrent validity between measures. Determining how assessment tools relate to each other is one way to help clinicians and experts in the field reach better conclusions on the use of measurement tools.

Summary and Conclusion

In recent years, the knowledge base on the vestibular system has grown tremendously. We now know that the vestibular system is crucial for normal development and functional performance. Yet, there is still much to learn about how to best assess this system. In practice, performance-based and parent-report measures are commonly used and presume to provide related information, yet the exact nature of these relationships is unclear. Consequently, there is a significant amount of variability in the literature and the field of occupational therapy about how to identify vestibular dysfunction. Often times, in practice and in recent research studies, a single parent-report measure indicating differences in vestibular processing has been used to identify vestibular dysfunction (Ahn et al., 2004; White et al., 2007). While both parent-report and performance-based measures have their advantages and short comings, it is unclear if both need to be administered in clinical or school-based settings. From both a research and a clinical standpoint, it would be useful to know how much these two modes of assessment overlap.

The aim of this study was to investigate whether parent-report responses on the SPM correlate and predict the results of the performance-based vestibular and balance measures in children. This study explored the relationships between such measures, clarified constructs, and furthered the field's knowledge on the vestibular system.

Chapter III

Methods

Research Design

The primary objective of this study was to investigate whether a parent-report measure of vestibular function, the Sensory Processing Measure (SPM), could predict the results of performance-based measures of vestibular function in children. Three specific aims were developed for this study, listed in order of importance:

1. **Determine if parent responses can predict the child's objective performance on performance-based vestibular measures**
2. **Determine what constellation of direct and indirect assessment items best predicts functional vs. dysfunctional vestibular performance**
3. **Describe the nature of the relationship between parent-report and performance-based measures of vestibular function**

To accomplish the aims of this study, we used a descriptive non-experimental design. We hypothesized that the SPM would correlate with at least one of the performance-based measures (i.e. the Balance subtest of the BOT-2, the SWAY app, or post-rotary nystagmus) and that the results from the SPM would be able predict the child's demonstrable use of vestibular processing as measured by at least one of the three performance-based vestibular measures.

Data analysis examined correlations and predictive capacities of the assessments within a group of children with known or suspected sensory processing challenges impacting their coordination. Analysis followed a three-part sequence. First, to answer the primary aim of the study, logistic regressions were used to determine the likelihood that the child would perform outside/below the average range on the performance-based measures; subtest level parent responses on the SPM were used as predictors and the performance-based measures served as dependent variables. Secondly, a receiver operating characteristic (ROC) curve analysis was used to examine how the predicted probabilities generated from the logistic regression compared to child's objective performance (i.e., examine the true positive versus false positive rate). The third and final step of data analysis was an exploratory analysis of correlations between the individual SPM item responses and various performance-based measures.

Sample. The target population was children in the United States with confirmed or suspected vestibular processing disorders. Because impaired coordination is a classic sign of vestibular dysfunction, and a common reason for referral to occupational therapy, the proposed study sought 30 child participants with known or suspected vestibular processing disorders affecting their coordination. A sample size of 30 was determined based on practical constraints and preliminary findings gathered from a feasibility study in which the recruitment response rate was 80%. A sample size of 30 would allow for a 39% power to detect an odds ratio of 2.5 using a two-sided test from a logistic regression.

Convenience sampling was used to recruit children from private outpatient occupational therapy clinics in Virginia and Maryland and a public charter school in the District of Columbia. Recruitment methods included flyers, email blasts, and direct contact. The proposed study's inclusion criteria was as follows: age 5-12 years old, have a known or suspected sensory processing disorder, challenges with motor coordination, able to follow simple verbal commands per parent or therapist's report, normal/ or corrected to normal vison, and are otherwise in good health. Identification of sensory processing disorders was done by licensed occupational therapists and confirmed by our research team using the SPM. Challenges with coordination were based on therapist report and qualification for therapy services under the ICD 10 code R27.8 (Lack of coordination).

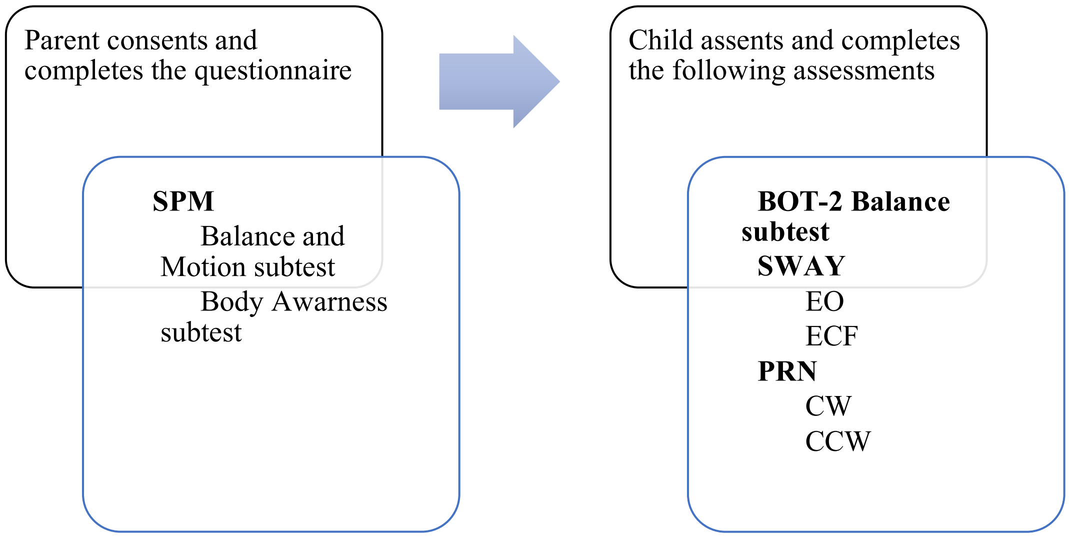
Subjects were excluded if they had a current or history of a seizure disorder, history of cancer or tumors, a traumatic brain injury, moderate to severe musculoskeletal abnormalities (including kyphosis, lordosis, scoliosis), muscular degenerative disorders, leg length discrepancies, active sinus infection, current ear infection, known history of motion sickness, cerebral palsy, limited range of motion in their arms or legs, hearing loss or other auditory disorder (i.e., conductive or sensorineural hearing loss, ear infection, tinnitus), or significant eye or vision problems (i.e., strabismus, nystagmus, diplopia). These exclusions were made as several of the above listed disorders commonly impact one's functional balance for reasons other than disordered vestibular processing and/or confound measurement readings. Originally, children were also excluded from the study if they had received 12 or more treatment sessions. This condition was removed as it severely limited enrollment.

Procedures. Parents interested in the study were contacted by a member of the research team at a mutually agreed upon time. The parents completed a phone screening (Appendix A) to gather relevant demographic information (e.g., pertinent medical history and a list of medication currently being taken) in order to determine the child's eligibility. During the phone screening, parents who wished to move forward were notified of their rights, possible risks, and the study procedures. They were given a chance to ask questions at that time. Those who agreed, provided a verbal consent and later signed a consent form on the day of testing. Once screened, parents of eligible children were emailed a copy of the consent form and an electronic version of the SPM parent questionnaire.

On the day of testing, parents were given time to ask questions regarding the consent form and then signed it while the examiner witnessed. Child participants were allowed to preview the testing room and equipment. The testing procedures were explained to them, at their level of understanding. Children who assented did so by writing their names on the assent form or gesturing their assent via nodding or signing 'yes.' Child participants were asked to complete a three-part battery of performance measures, administered in a quiet environment with the examiner. Each measure is described in greater detail in the following section.

Figure 5

Assessments and Subtests in the order in which they were Administered



Note: SPM= Sensory processing Measure- Home Form; BOT-2= Bruininks- Oseretsky Test of Motor Proficiency- second edition; EO=Eyes open; ECF= eyes closed on Foam; CW= clockwise, CCW= counter clockwise

Study Measures

All subjects were asked to complete the battery of performance-based assessments of vestibular functioning shown in Figure 5. Assessments include the Balance subtest of the Bruininks- Oseretsky Test of Motor Proficiency (BOT-2), the modified Clinical Test of Sensory Integration on Balance (mCTSIB) protocol of the SWAY application, and the vestibular ocular reflex (VOR) as measured by the duration of the child's post-rotary nystagmus (PRN), in this order. The battery of assessments was administered by a licensed occupational therapist who has eight years of clinical experience, advanced studies in sensory integration, and has demonstrated proficiency in administering each assessment. Prior to their participation, parents were read a condensed version of the consent form and had the option of moving forward or discontinuing their participation. Consenting parents of eligible children completed either the online or paper version of the SPM on the day of testing. The parent questionnaires, completed online, were stored electronically using automated scoring software via an online platform. All other assessments were scored manually using the administration manuals and stored securely in compliance with the university's IRB requirements. Logistic regressions were used to predict the likelihood that the subjects' performance would be "functional" or "dysfunctional." To accomplish this, the results of each performance-based outcome measure were dichotomized as "functional" or "dysfunctional" based on that measures' published cutoff ranges of average and below average performance. The SWAY application was the only exceptions, as there is no published normative ranges.

Sensory Processing Measure. The SPM is a valid and reliable normative- referenced caregiver questionnaire designed to help identify sensory processing difficulties in children five to 12 years old (Parham et al., 2007). It contains 75 statements that shed light on how the child responds to sensory input and their ability to use such input to support participation in everyday tasks. The 75 statements are divided into eight subtests: Social Participation, Vison, Hearing, Touch, Taste and Smell, Body Awareness, Balance and Motion, and lastly Planning and Ideas. In this study, caregivers completed the entire questionnaire rating their child's behaviors on a four-point frequency linkert scale: *(1) Never, (2) Frequently, (3) Occasionally,* or *(4) Always*. Elevated scores reflect greater levels of dysfunction. Each subtest yields a raw score, which is converted into a T-score, and finally translated into a descriptive category. T-scores between 40-59 indicate *typical* functioning. T-scores between 60-69 suggest that the child may be experiencing *Some Problems.* T-scores between 70-80 fall in the *Definite Dysfunction* category. For the sake of analysis, descriptive categories were condensed such that any score above the typical range were classified by the research team as dysfunctional. While parents were asked to complete the entire SPM form, as seen in Figure 5, the Balance and Motion (vestibular) and Body Awareness (Proprioception) scales were the focus of analysis based on the interconnectedness of these two systems, previously discussed in chapter two. The Balance and Motion subtest of the SPM examines vestibular modulation, seeking behaviors, and postural control through questions that seek to uncover possible vulnerabilities in the system that may impact motor performance and functional participation (Parham et al., 2007). The Balance and Motion subtest has 11 statements and questions such as: Does your child "seem not to get dizzy when others usually do?", "Shows distress when his or her head is tilted away from the upright vertical position" and "shows poor coordination and appear to be clumsy" (Parham & Ecker, 2007). The Body Awareness Scale has 10 items that contains statements and questions about how a child uses proprioceptive input. Questions in this section seek to expose possible seeking behaviors and perception issues. Statements include: “Grasps objects (such as a pencil or spoon) so tightly that it is difficult to use the object?” “Seems driven to seek activities such as pushing, pulling, dragging, lifting, and jumping?”, and “Seems unsure of how far to raise or lower the body during movement such as sitting down or stepping over and object?” (Parham & Ecker, 2007). The SPM allows for subtest scores to be examined individually and for items within each subtest to be examined in order to reveal patterns in sensory related behaviors. The item-level responses were used during the third tier (the exploratory portion) of the data analysis.

Missing data. The SPM results were stored in a secure online database controlled by the Western Psychological Services publishing company. This online platform alerts the research team when the questionnaire is submitted with missing items. If a parent submitted the questionnaire with missing data, a link to the same questionnaire was resent soliciting its completion. If the parent failed to complete the missing items in a reasonable amount of time, the following occurred which is in accordance with the scoring procedure stated in the SPM manual. First, if there were eight or more missing responses then the questionnaire would not be scored (Parham et al., 2007). Second, if there were seven or fewer missing items, median values were used in their place, and scoring and interpretation will proceed as usual (Parham et al., 20017).

Psychometric Properties. The items on the SPM were generated based on the principles of SI theory and have undergone several revisions and rounds of expert review to ensure adequate content validity (Parham et al., 2007). Overall, the SPM shows moderate convergent validity with the Dunn’s Sensory Profile (SP) ($\rho = 0.86$, $p < .01$) (Brown, Morrison & Stagnitti, 2010). More specifically, the SPM manual reports strong correlations between subsets of the SPM and SP when examining comparable aspects of sensory processing (Parham et al., 2007). For example, the Balance and Motion Subtest of the SPM has a 0.48 correlation to the Vestibular Processing subtest of the SP, and a .47 correlation between the Body Position and Movement (subtest of the SP) (Parham et al., 2007). Internal reliability for the

SPM and its component subscales range from ⟨=0.770-0.95 and inter-rater reliability r>0.94 (Parham et al., 2007).

The SPM, like questionnaires in general, provides an idea of the child's behavior patterns over time, seen in their natural environment (Lalor et al., 2016). It also gives insight into how sensory issues impact functional performance and participation. Performance-based measure capture only what can be directly observed during an evaluation, i.e., a snapshot of their true performance on a single day. The SPM was selected for this study because it is psychometrically sound, easy to administer, and easy to score. Furthermore, a review of the available research on this measure revealed that it is in line with the current theories of sensory specific responsiveness used in the field today.

Bruininks Oseretsky Test of Motor Proficiency- Second Edition. The BOT-2 is a performance-based measure that requires direct observation of both fine and gross motor skills. The BOT-2 is a standardized measure given to children and adults age four to 21. The full test is made up of eight subtests, each of which can be individually administered and scored. For the purposes of this study, only the Balance subtest was administered and scored, as it is the subtest most commonly used to infer vestibular functioning. The Balance section of the BOT-2 is made up of nine items, seven of which are timed. During the timed items, the child is asked to hold static single leg and bipedal balance postures, each for up to 10 seconds. The child assumes the balance positions with their hands on their hips first with their eyes open and later with their eyes closed. The untimed portions include walking six steps on a line, first using a typical stride and later using six heel-toe steps. Raw scores are generated for each of the nine items, and a total point score is then summed. Lower scores are indicative of greater levels of dysfunction. The child's total point score for this subtest places them in one of four descriptive categories: *Well Above Average, Above Average, Average, Below Average, or Well Below Average* depending on how their performance compares to their age and sex matched peers. For the purposes of analysis, descriptive categories that indicated below average performance or worse were recoded as "dysfunctional," while children who score average or better were classified as "functional."

The BOT-2 is the latest edition of this particular assessment. It has undergone revisions to include a wider normative sample (N= 1,520) representative of disperse geographical regions of the U.S, including families with varied socioeconomic status and ethnicities (Deitz et al., 2007). It has moderate to strong convergent validity with the Peabody Developmental Motor Scales (PDMS-2); *PDMS-2* Gross Motor Quotient and *BOT-2* Body Coordination, *adj r* = 0.65; *PDMS-2* Gross Motor Quotient and *BOT-2* Strength and Agility with full push-ups, *adj r* = 0.75 (Deitz et al., 2007). Concurrent validity ranges from adj. r=0.51-0.70+ and inter-rater reliability ranges from adjusted r =.86->90) (Bruininks & Bruininks, 2005; Deitz et al., 2007).

The BOT-2 was chosen for this study because it is one of the most commonly used measures of motor skill in the world (Kennedy et al., 2012). It is also a very cost-effective measure, appropriate for very young children, and can be administered in a timely fashion (Said, 2015). Furthermore, the BOT-2 offers quantifiable measures of balance and postural control in various conditions (e.g., eye open and eye closed) which isolates/reduces visual contributions to balance.

SWAY Balance application. The SWAY Balance mobile application has been cleared by the Food and Drug Administration as a vestibular analysis apparatus. The Modified Clinical Test of Sensory Interaction (mCTSIB) module of the SWAY Balance application is one of several offered by the application. Testing procedures require that the mobile device be positioned against the subject's chest while standing under various conditions. For the purposes of this study, the mobile device was secured to the participant's chest using a harness while the child stood with their arms folded over their chest. To eliminate the variability that wearing different types of shoes would introduce, subjects were instructed to take off their shoes and stand in socks or bare feet. The mobile device was calibrated for each participant before running the modules. See Appendix B for a visual of the four stance conditions. The first testing condition (1) participant stand on a firm (static) surface with their eyes open (EO) for 30 seconds, (2) participants stand on a firm surface with their eyes closed (EC), (3) subjects stand on a foam cushion (2" high, 15" long, and 18.25" wide) with their eyes open (EOF), and the final condition (4) subjects stand on the foam cushion with their eyes closed (ECF). The mobile device recorded the child's postural sway via proprietary accelerometers within the mobile device. The examiner stood within close proximity of the subject to prevent possible injurious falls and to record the number of corrective steps (taken to avoid a fall). The child's performance under the fourth condition (eyes closed, on foam) was of particular interest as "tasks with reduced proprioceptive and visual cues (e.g., standing on foam, eyes closed) are most sensitive for an otolith disorder" (Basta et al., 2005). The application generated a balance score based on proprietary algorithms using data from the accelerometers (Patterson et al., 2014). Higher scores, indicated less postural sway (i.e., better postural stability), and lower scores indicated greater levels of postural sway (i.e., less postural stability).

The SWAY Balance application was selected because it is an objective measure of postural sway. The mCTSIB module was selected over other modules offered by the SWAY Balance application because it involves only bi-pedal balance postures. Other modules involving single-leg stances introduce gender differences as females typically outperform males in single leg balance postures (Anderson, Gaten, Glatts, & Russo, 2017). No gender-specific differences were seen in bipedal balance postures (Anderson et al., 2017). Advantages of the SWAY application are that it has a strong correlation (r=.632, p,.01) with balance platform data, yields quantitative scores, and uses small easily transportable equipment (Patterson et al., 2014). The SWAY Balance application is commonly used as a repeated measure where the individual's baseline measure serves as his/her own control. As such, there are no published normative ranges on the amount of postural sway indicative of dysfunction. Therefore, the results of this measure were not transformed into a dichotomous (functional vs. dysfunctional) variable, and data were used in the analysis only for Aim 2 and Aim 3 of this study (See Table 1).

Post-rotary nystagmus. PRN is a commonly used indicator of vestibular function. When seated, PRN measures the function of the horizontal semicircular canal (Gutman, 20018). To elicit PRN, subjects sat cross-legged on a rotation board, with their head tilted into 30 degrees of downward flexion while wearing Frenzel goggles. Having the child assume a downward flexion position is widely accepted in the literature, as it aligns the horizontal semicircular canal (hSCC) in the correct yaw (horizontal) rotational plane (Mulligan, 2011; Su et al., 2015) which maximizes hSCC stimulation (Juhola, Aalto, Jutila et al., 2011). To help maintain correct positioning, the subject wore a soft foam cervical collar. The subjects were manually rotated in two separate sets of rotation. First, children were rotated 10 times in a clockwise direction and then abruptly stopped. They were rotated a second time in a counter-clockwise direction, and then abruptly stopped as before. The examiner observed the response of the child's eyes each time (after the "stop") for PRN. Subjects received a two to three-minute break between clockwise and counter clockwise rotations. The duration of the PRN response was recorded to the nearest whole second. The typical range for PRN is 8-22 seconds (Gutman, 2008). Children scoring within this range were classified by the research team as "functional" while subjects who exhibit PRN longer or shorter than this range were classified as "dysfunctional".

Subjects were rotated in a dark room while wearing Frenzel goggles to maintain the integrity of the PRN response. Frenzel goggles are a noninvasive tool used to reduce visual fixation by means of high magnifying lenses. The goggles have a built in light source that allow the examiner to observe eye movement [in the dark] (Strupp et al., 2014). The PRN response can be paroxysmal in children with vestibular processing disorders. Because of the transient and spasmodic nature of the reflex, this portion of testing was recorded on a mobile device. The recording was analyzed after the testing day and its duration on the response was recorded in REDCap® electronic data capture tool hosted at Virginia Commonwealth University.

Data Analysis

Table 1 describes the statistical procedures that were used to answer each research question. Due to limited enrollment and subsequent limitations in statistical power, analysis was adjusted to uncover meaningful relationships between variables and to describe noteworthy patterns in the data (Tabachnick & Fidell, 2013). *Meaningful relationships* were determined by examining the goodness of fit of the ROC curves. The area under the curve (AUC) of the ROC curve was used to quantify the overall ability of the SPM scores to discriminate between functional and dysfunctional outcomes. "A perfect test will have a [AUC] value of 1.0 (no false positives and no false negatives), whereas values of 0.5 suggests the test result is not better than if determined by chance alone" (Carter, Pan, Rai, & Galandiuk, 2017, p.1644). A test with an AUC of .70 is considered *fair* (Carter et al., 2017; Metz, 1978). As such, this cutoff was used to denote meaningful relationships.

Table 1

Statistical Procedures and Research Questions

Specific Aims		Statistical Analysis	variables	
Determine if parent responses can predict the child's objective performance on performance-based based vestibular measures	**RQ1:** Are parent perceptions of their child's vestibular function, as measured by the SPM, predictors of the child's objective performance?	Separate logistic regressions were used determine the likelihood that the child's performance were outside/ below the average range on the listed outcome measures	**Predictors**	**Outcome**
			BAL	BOT PRN CW PRN CCW
			BOD	BOT PRN CW PRN CCW
	RQ2: What cutoff ranges on the SPM best discriminate functional vs. dysfunctional performance?	ROC Curve was completed first to test the sensitivity of the existing cutoff ranges established by the SPM that discriminate between functional and dysfunctional vestibular performance. Then analysis will determine what cutoff ranges maximize the true positive rate and minimize the false negative rate in identifying vestibular dysfunction Area under the curve: .90-1= Excellent .80-.89=good .70-.79=fair .60-.69= poor .50-.59=fail	Predicted probabilities compared to the child's objective performance. Results =.5% indicate a poor model, no better than random chance Results closer to 1 indicate a good predictive model	
Determine what constellation of direct and indirect assessment items best predicts	**RQ 3:** Which parent response items, and measures best	Exploratory analysis of the data using logistic regression and feedforward (stepwise) selection of variable	**Predictors**	**Outcome**
			BOD BOD_2	BOT_2
			BAL BAL_2	

functional vs. dysfunctional vestibular performance	discriminate functional vs. dysfunctional vestibular processing as measured by the BOT-2?	Wald statistic to determine the coefficient of each predictor is significantly different from 0 Odds ratio using condensed descriptive categories of the BOT-2 to determine whether including a predictor better predicts functional vs. dysfunctional vestibular performance	SWAY SWAY EO SWAY ECF	
			PRN CW PRN CCW	
			LOB	
Describe the nature of the relationship between parent-report and performance-based measures of vestibular function	**RQ4:** Is there a relationship between parent's item-level responses on the SPM and performance-based measures of vestibular function?	Spearman Rho correlations was used to first see how the BOD and BAL subtests scores correlate with each outcome measure and then again to see how specific items in the two subtests relate to each performance measure Coefficients between 0-.10= very small .10-30= small .30-.50=moderate .50-.70=large .70-.90= very large	**Variable (a)**	**Variable (b)**
			BAL	BOT PRN CW PRN CCW SWAY SWAY EO SWAY ECF
			BAL_2	BOT PRN CW PRN CCW SWAY SWAY EO SWAY ECF
			BOD	BOT PRN CW PRN CCW SWAY SWAY EO SWAY ECF
			BOD_2	BOT PRN CW PRN CCW SWAY SWAY EO SWAY ECF

Note: BAL= T score of Balance and Motion scale of SPM; **BOD**= T score of Body Awareness scale of the SPM; **BOT**= scale score of BOT-2 Balance subtest; **PRN CW**= duration on PRN following clockwise rotations**, PRN CCW**= duration of PRN following counter clockwise rotation; **BOD_2=** items responses in the Body Awareness scale of the SPM**; BAL_2=**item responses in the Balance and Motion scale of the SPM; **BOT_2=**Condensed categories of BOT-2 results (i.e. functional vs. dysfunctional); **LOB**= instances of LOB or corrective step to prevent a fall; **SWAY**=overall postural sway score, **SWAY EC**= Sway score with participants eyes closed on a solid surface; **SWAY ECF**= sway score in proprioceptive and vision reduced conditions (i.e. in eyes closed on foam)

Data collection and cleaning. Data was collected, coded, and stored on a password protected laptop using REDCap® (Vanderbilt, Tennessee). Data analyses was performed using SPSS 26 (IMB Corporation, Armonk, NY). Descriptive statistics were used to summarize the sample's demographic information (e.g., age, race, and gender) and the results of each measure (e.g. percentage of the subjects in age range, gender, and ethnicity demonstrate abnormal balance and vestibular signs). Data were screened for outliers and multicollinearity. Outliers were defined as scores one or more standard deviations away from the sample's mean. Analysis was performed with the outliers and again without them in order to determine the impact that these scores had on the overall dataset. To test for multicollinearity, researchers examined collinearity statistics (e.g., tolerance and variance inflation (VIF) values). As commonly accepted in the literature, tolerance values smaller than 0.1 and VIF values larger than 10, indicated a major problem with collinearity (Field, 2011). In situations where a suspected problem with collinearity was present, analysis continued to uncover possible ill-conditioned eigenvalues and variance proportions (Field, 2011). The data were reviewed to identify predictors that accounted for large amounts of variance with relatively small eigenvalues. The presence of this would suggest that the regression coefficients were dependent and subsequently that the model is biased (Field, 2011). While the presence of collinearity would not be ideal in determining a predictive relationship, this finding would still provide useful information to the field. To ensure that the outcome was not perfectly separated, the research team monitored the outcome and predictors as data were collected and entered into the RedCap® system.

Analysis. As seen in Table 1, the first aim of the study was to determine whether parent responses were significant predictors of the child's actual performance. To test this hypothesis, separate logistic regressions were performed with the SPM subtests as predictors and each performance-based measure as the outcome variables. Logistic regression was chosen for this study because it is an accommodating strategy, with fewer restrictions, and is well suited to handle the mix of variables used in this study. Furthermore, logistic regressions make no direct assumptions about the distribution or the linear relatedness of the predators to the dependent variables (Tabachnick & Fidell, 2013). Instead, it assumes that there is a linear relationship between continuous predictors and the *logit transform* of the dependent variables (Tabachnick & Fidell, 2013).

To address research question two, a receiver operating characteristic (ROC) curve was conducted to test the sensitivity of the existing cutoff ranges established by the SPM that discriminate between functional and dysfunctional vestibular performance. This analysis determined the cutoff ranges that maximized the true positive rate (i.e., the level that yields at least 80% sensitivity) and minimized the false negative rate in identifying vestibular dysfunction. In so doing, emphasis was intentionally placed on maximizing sensitivity over specify. This distinction is important to make in clinical settings particularly when evaluating and screening for dysfunction. During initial phases of examination, clinicians prioritize early identification of possible signs of dysfunction to capture those who may warrant further testing.

To determine what constellation of assessment items best predict functional vs. dysfunctional vestibular performance (Aim 2), forward selection logistic regression was used as there was no known ordering of the independent variables. Predictors included both the performance-based results (measures of postural sway, instances of loss of balance, and PRN) along with parent-report responses (specific items and composite T-scores) from the SPM subscales of interest (Balance and Motion and Body Awareness) to determine which measures best predict functional vs. dysfunctional vestibular function as classified by the BOT-2's condensed descriptive categories.

Finally, to describe the nature of the relationship between parent responses and performance-based measures (Aim 3), Spearman Rho correlations were performed using both SPM subtest scores and item level responses. The magnitude, not the direction or p-value, related to the correlations were considered in describing the nature of the relationship between variables.

Chapter IV

Results

Sample Characteristics

While the target sample size of the study was 30 subjects, the onset of COVID-19 prevented the study from reaching the target sample size. A total of 27 child participants with known or suspected sensory processing disorders affecting their coordination enrolled in the study. Twelve children were recruited from outpatient clinics in the District of Columbia (DC) metro area and 15 were recruited from a DC public charter school. All subjects met the inclusion criteria. Twenty-five of the 27 participants were able to tolerate the full assessment battery. The two children who did not complete the full test battery refused the PRN portion due to either a known sensory aversion to light near eyes (a necessary component of objectively measuring post-rotary nystagmus) or an unspecified refusal.

Table 2 displays the demographic composition of the sample. The average age of the sample was 99.3 months (8.3 years). Of the 27 children tested, 21 were male (77.8%) and 6 were female (22.2%). Table 2 also shows how the research team used two of the performance-based measures, to classify the sample in one of two groups, functional or dysfunctional vestibular performance. The most important aim of the study was to determine if parent responses could predict the child's objective performance on performance-based measures of vestibular function. As seen in Table 2, each performance-based measure has a different threshold for classifying Average (functional) and Below Average (dysfunctional) performance. Across performance-based measures, the Balance subtest of the BOT-2 classified the largest percentage (55%) of subjects as Below Average. The measures of post-rotary nystagmus classified between 25.9%-33.3% of the sample as having dysfunctional vestibular performance. This was an expected finding due to the naturally wide range of the typical duration of PRN seen in young children. Descriptive information about how the research team used information from the SWAY application to classify subjects into Functional and Dysfunctional groups does not appear in this table because there is no published normative data to determine a typical range necessary to make this distinction.

Since certain medications can impact vestibular responses, all parents were asked to record whether their child was currently taking any form of medication. One caregiver reported that their child routinely takes medication to treat the child's Attention Deficit Hyperactive Disorder (ADHD). That caregiver opted not to give the child this medication on the day of testing. No other children were reported to take routine medications, and none were noted to be medicated on the day of testing.

Table 2

Demographic Characteristics of Participants Classified as Functional vs. Dysfunctional

				Direct Measures of Vestibular Function					
				BOT-2		PRN CW		PRN CCW	
		n	Sample %	Func(%)	Dys(%)	Func(%)	Dys(%)	Func(%)	Dys(%)
Gender	Male	21	77.8	9 (33.3)	12 (44.4)	13(48.1)	8 (29.6)	15 (55.6)	6(22.2)
	Female	6	22.2	3 (11.1)	3 (11.1)	5 (18.5)	9 (33.3)	5 (18.5)	1 (3.7)
Age in months	60-95	14	51.9	7(25.9)	7 (25.9)	9 (4.5)	5 (18.5)	11(40.7)	3 (11.1)
	96-131	10	37.0	3 (11.1)	7 (25.9)	6 (22.2)	4 (14.8)	7 (25.9)	3 (11.1)
	132-155	3	11.1	2 (7.4)	1 (3.7)	3 (11.1)	0	2 (7.4)	1 (3.7)
Race	African American	13	48.1	5 (18.5)	8 (29.6)	9 (33.3)	4 (14.8)	10 (37.0)	3 (11.1)
	Caucasian	14	51.9	7(25.9)	7(25.9)	9 (33.3)	5 (18.5)	10 (37.0)	4 (14.8)
Total		27		12 (44.4)	15 (55.6)	18 (66.7)	9 (33.3)	20 (74.1)	7 (25.9)

Note: PRN CW= Clockwise Post-rotary Nystagmus; PRN CCW= Counterclockwise Post-rotary nystagmus; BOT-2= Balance subtest of the Bruininks Oseretsky Test of Motor Proficiency Ed 2; Func= Functional performance; Dys= Dysfunctional Vestibular performance

Preparing Data for Analysis

The data passed validation checks in SPSS for problematic or invalid cases. No problematic cases were identified. No multivariate outliers were identified in the data set. There were three univariate outliers present in the data set. The sample was also checked for collinearity. The results of the collinearity diagnostics are reported in Table 3. As commonly accepted in the literature, tolerance values less than 0.1 (Menard 1995 as cited in Fields 2011) and VIF values greater than 10 indicate a serious problem with multicollinearity (Meyers 1990 as cited in Fields 2011). In examining the VIF values (see

Table 3) no multivariable analyses demonstrated multicollinearity as all VIF values were under 2. Additionally, no influential observations were detected using Cook's D; as all values were <1 (maximum Cook's D=.53). Based on these metrics, it was determined that the univariate outliers did not have an unnecessarily large influence on the regression and the full sample (outliers included) was included in the planned analysis.

Table 3

Collinearity Diagnostic Table

Parent-report	Complete Sample		Sample without Outliers	
	Tolerance	**VIF**	**Tolerance**	**VIF**
BOD T-score	.812	1.23	.822	1.23
BAL T-score	.812	1.23	.822	1.23

Note: Dependent variable= BOT-2;

Parent-report	Complete Sample		Sample without Outliers	
	Tolerance	**VIF**	**Tolerance**	**VIF**
BOD T-score	.788	1.27	.796	1.26
BAL T-score	.788	1.27	.796	1.26

Note: Dependent variable= PRN CW

Parent-report	Complete Sample		Sample without Outliers	
	Tolerance	**VIF**	**Tolerance**	**VIF**
BOD T-score	.788	1.27	.796	1.26
BAL T-score	.788	1.27	.796	1.26

Note: Dependent variable= PRN CCW

Results Related to the First Specific Aim (RQ 1-2, see Table 1)

The first specific aim of the study was to determine if parent responses on the Balance (BAL) and Body Awareness (BOD) subtests of the Sensory Processing Measure (SPM) could predict the child's performance on objective measures of vestibular functioning (Balance subtest of the BOT-2, post-rotary nystagmus, and the SWAY application). Table 4 shows the two SPM subtest scores of interest, along with their corresponding odds ratios and ROC curve analysis.

Table 4

Unadjusted Logistic Regressions of Parent-report data and Direct Measures

Parent Report	**Performance Measures**	**Odds Ratio 95%Confidence interval**	**lower**	**upper**	**P value**	**R^2**	**ROC Curve 95% Confidence Interval AUC**	**lower**	**upper**
BAL T-score	PRN CW	0.97	0.87	1.09	0.64	0.011	0.42	0.20	0.64
	PRN CCW	1.06	0.92	1.22	0.39	0.043	0.59	0.36	0.82
	BOT-2	1.16	0.99	1.35	0.06	0.222	0.73	0.53	0.92
BOD T-score	PRN CW	0.96	0.85	1.09	0.53	0.020	0.47	0.22	0.72
	PRN CCW	1.07	0.91	1.24	0.43	0.038	0.59	0.35	0.84
	BOT-2	0.99	0.88	1.11	0.86	0.002	0.54	0.32	0.76

Note: BAL T-score: Balance subtest of Sensory Processing Measure; BOD T scores: Body Awareness subtest of the Sensory Processing Measure; PRN CW: clockwise post-rotary nystagmus; PRN CCW: counter clockwise post- rotary nystagmus; BOT-2: Bruininks-Oseretsky Test of Motor Proficiency- Balance subtest.

As noted in the methods section, meaningful relationships were those that have AUC of .70 or better. Those below this cutoff are considered poor predictors. Overall, there was a meaningful relationship observed between parent responses on the Balance and Motion subtest of the SPM and the child's performance on the Balance subtest of the BOT-2. Figure 6 shows that with an area under the curve of 0.728 (standard error= .10, 95% CI= .53-.92), the predicted probabilities of the parent reported BAL T-scores predict the child's performance on the Balance subtest of the BOT-2 with *fair* accuracy (Metz, 1978). As such, the BAL T-score was determined to be a *fairly* useful predictor of the child's performance on the Balance subtest of the BOT-2. With AUCs no better than .59 across performance-based measures and an accuracy of 53.9% (standard error= .114, 95% CI .32-.76) in predicting the child's performance on the Balance subtest of the BOT-2, the BOD T-score was not a meaningful predictor of the child's objective performance on the BOT-2 or any of the direct measures of vestibular function.

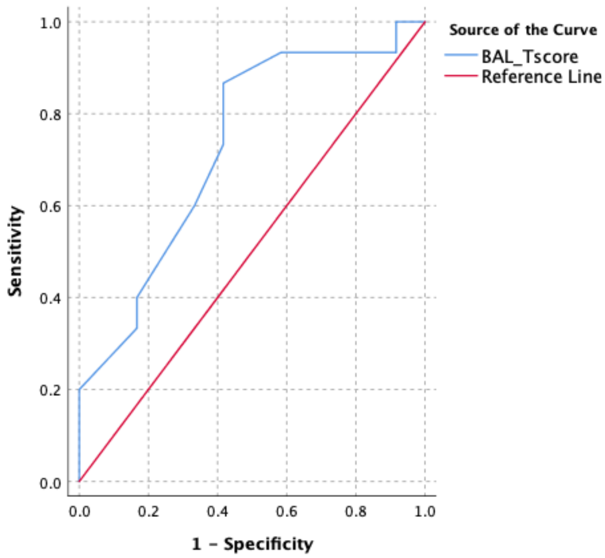
The SPM uses T-scores between 40 and 59 as cutoffs for functional sensory processing. Children with T-scores 60 and above are believed to have some level of dysfunctional sensory processing. Comparatively, children who scored below the average range on the Balance subtest of the BOT-2 were classified as having a vestibular dysfunction. The BAL T-score cutoff of 60 had an accuracy of 73.3%. Of those who were not classified as having a vestibular dysfunction by the research team, the model correctly identified them with 58.3% accuracy.

Additionally, as noted in Table 4, the Balance T-score accounted for 22% if the variance in the BOT-2 score and 1%-4% of the variance in PRN CW and PRN CCW respectively. The BOD T-score accounted for 3% or less of the variance in PRN CW, PRN CCW, and BOT-2. In general parent responses, summarized by the BOD subtest score, did not show a predictive relationship with any of the performance-based measures included in this portion of the study.

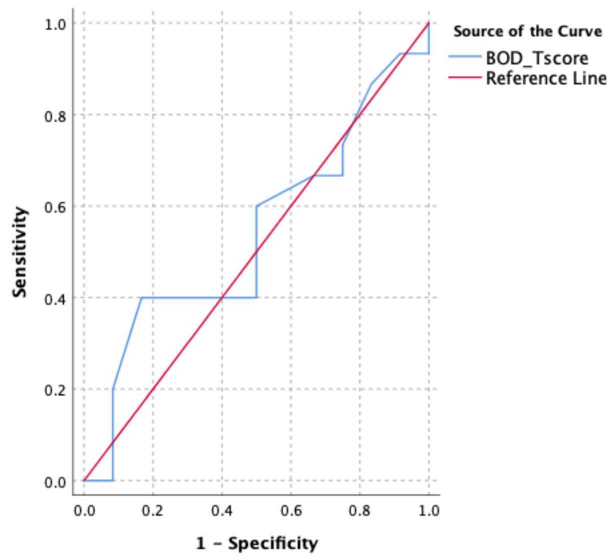
Figure 6

ROC Curve Analysis of Parent-report subtest scores and Direct Measures

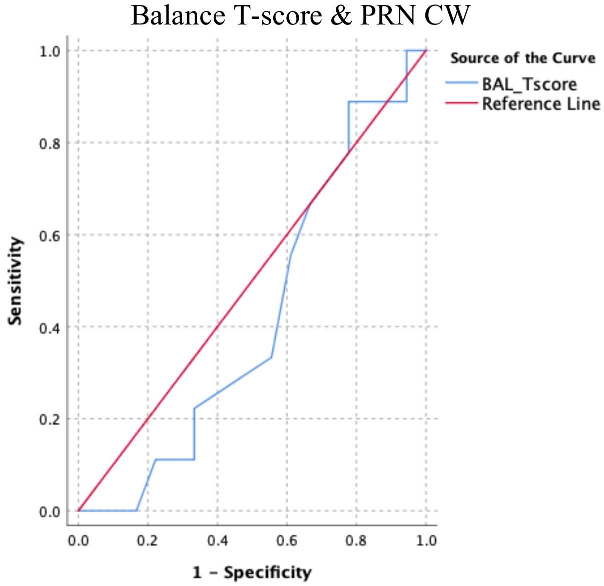
Balance T-score & BOT-2



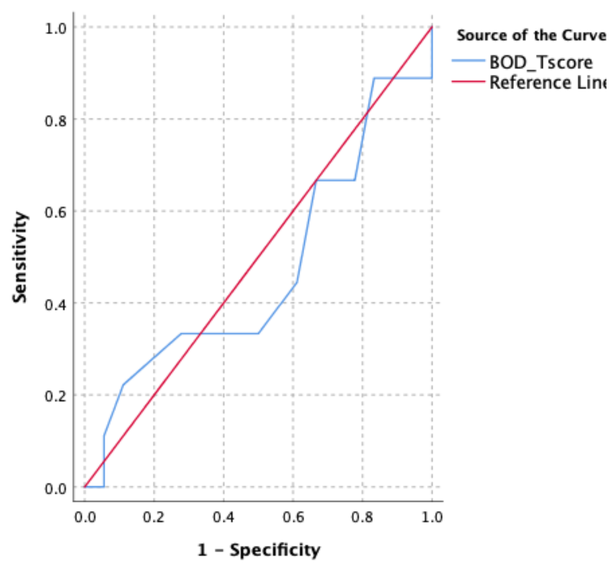
BOD T-score & BOT-2



Balance T-score & PRN CW

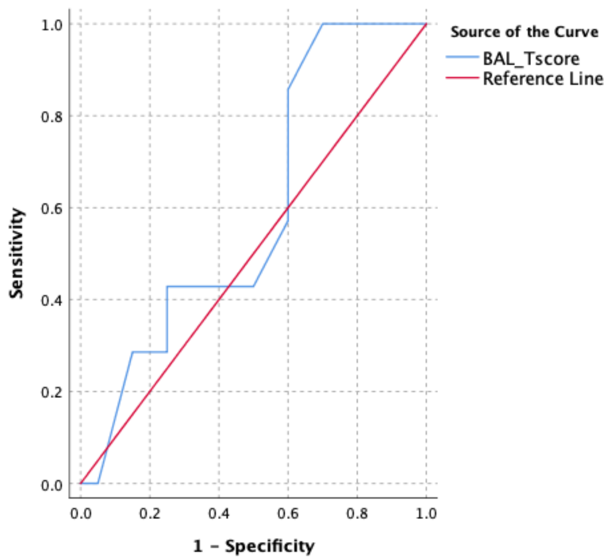


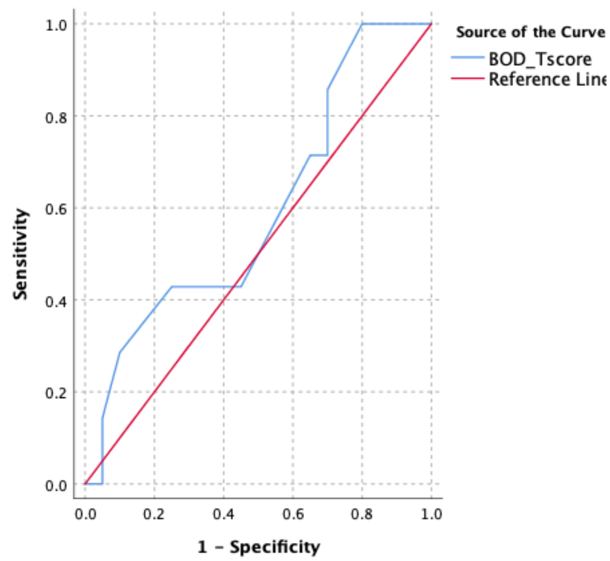
BOD T-score & PRN CW



Balance T-score & PRN CCW

BOD T-score PRN CCW





Results Related to the Second Specific Aim (RQ 3, see Table 1)

The second specific aim of the study was to determine the constellation of direct and indirect measures that best predict functional and dysfunctional vestibular performance. Forward selection logistic regression was used to answer this question. The BAL T-score as well as the item responses, BOD T-score, and BOD item responses, along with the SWAY and its component subtest, PRN CW, PRN CCW, and instances of loss of balance were entered into the regression. After entering in all the variables into this adjusted model, the SWAY (SE=.05, Wald=5.00, EXP (B)= 0.895) was the only variable that was related to predicting the child's performance on the Balance subtest of the BOT-2.

Results Related to the Third Specific Aim (RQ 4, see Table 1)

The third and final specific aim of the study was to describe the nature of the relationship between parent-report and objective measures of vestibular function. Spearman Rho correlations were used to uncover the relationship between parent responses (at the subtest level and item level) and the objective measures. The absolute value of the correlation coefficients are summarized in a heat map in Table 5. Correlations with larger magnitudes are indicated by a darker shade of orange. Additional details on the exact nature of the correlations (direction, significance, and sample size) are found in the appendix

Table B1.

Overall, there were *moderate* correlations (Field, 2011) seen at the subtest and item level when examining the relationship between parent responses on the BAL subtest and the direct measures. *Moderate* to *large* correlations were observed between item level parent responses on the BOD subtest and the direct measures. The largest correlation being between item 50 in the Body Awareness subtest and the SWAY EO subtest. The relationships are discussed further in the Discussion chapter.

Table 5

Correlations Between Parent-report and Direct Measures

	BOT Scale Score	PRN CW	PRN CCW	SWAY	SWAY EO	SWAY ECF
BAL T-score	0.36	0.09	0.22	0.23	0.17	0.31
BAL item 56 Seem excessively fearful of movement , such as going up and down stairs	0.15	0.06	0.24	0.28	0.43	0.03
BAL item 57 Have good balance?	0.35	0.08	0.18	0.26	0.32	0.15
BAL item 58 Avoid balance activities?	0.27	0.26	0.46	0.24	0.31	0.10
BAL item 59 Fall out of chair when shifting his or her weight?	0.14	0.37	0.01	0.06	0.16	0.01
BAL item 60 Fail to catch himself or herself when falling	0.06	0.04	0.06	0.05	0.16	0.08
BAL item 61 Seem not to get dizzy when others usually do?	0.17	0.25	0.11	0.04	0.09	0.13
BAL item 62 Spin and whirl his or her body more than other children?	0.14	0.48	0.17	0.32	0.29	0.21
BAL item 63 shows distress when his or her head is tilted away from an upright, vertical position	0.18	0.24	0.28	0.23	0.28	0.17
BAL item 64 Show poor coordination and appear clumsy	0.34	0.12	0.21	0.07	0.13	0.08
BAL item 65 Seem afraid of riding in elevators or on escalators	0.16	0.03	0.09	0.13	0.08	0.06
BAL item 66 Lean on other people or furniture when sitting or when trying to stand up?	0.31	0.06	0.10	0.17	0.19	0.14

BOD T-score	0.16	0.19	0.23	0.06	0.02	0.10
BOD item 46 Grasp object objects (such as a pencil or spoon) so tightly that it is difficult to use the object?	0.15	0.31	0.39	0.02	0.13	0.12
BAL item 47 Seem driven to seek activities such as pushing, pulling dragging, lifting, and jumping	0.07	0.00	0.01	0.03	0.17	0.17
BOD item 48 Seem unsure of how far to raise and lower the body during movement such as siting down or stepping over an object?	0.39	0.20	0.32	0.41	0.33	0.34
BOD item 49 Grasp objects (such as a pencil or spoon) so loosely that is it difficult to use the object?	0.42	0.38	0.39	0.28	0.34	0.04
BOD item 50 Seem to exert too much pressure for the task such as walking heavily, slamming doors or pressing too hard when using pencils or crayons?	0.31	0.20	0.17	0.44	0.60	0.23
BOD item 51 Jump a lot?	0.13	0.04	0.02	0.13	0.15	0.03
BOD item 52 Tends to pet animals with too much force?	0.30	0.07	0.08	0.07	0.20	0.02
BOD item 53 Bump or push other children?	0.30	0.14	0.12	0.08	0.15	0.08
BOD item 54 Chew on toys, clothes, or other objects more than other children?	0.20	0.01	0.10	0.15	0.17	0.02
BOD item 55 Breaks things from pressing or pushing too hard on them?	0.07	0.25	0.13	0.02	0.34	0.19

Note: BAL T-score: Balance subtest of Sensory Processing Measure; BAL item#= item response in Balance and Motion subtest of Sensory Processing Measure; BOD T scores: Body Awareness subtest of the Sensory Processing Measure; BOD item#= item response in Body Awareness subtest of Sensory Processing Measure PRN CW: clockwise post-rotary nystagmus; PRN CCW: counter clockwise post- rotary nystagmus; BOT-2: Bruininks-Oseretsky Test of Motor Proficiency- Balance subtest; SWAY= overall SWAY score; SWAY EO= SWAY eyes open; SWAY ECF= SWAY subtest with eyes closed standing on foam

Chapter V

Discussion

In the field of occupational therapy, there is a need to explore the relationship between performance-based measures and parent-report measures of vestibular functioning because thorough assessment sets the foundation for effective intervention. A better understanding of how parent-report measures and performance-based measures relate to one another can inform clinicians about what information can be inferred from test results and, equally as important, what inferences should not be made. The primary objective of this study was to determine if subjective parent-report data of sensory processing could be used to predict the child's abilities on performance-based measures of vestibular performance. The results of this study were also intended to determine what constellation of direct and indirect assessment items best predicts functional versus dysfunctional vestibular performance. Lastly, the study was designed to describe the nature of the relationship between parent-report and performance-based measures of vestibular function. We hypothesized that the information collected from the SPM could predict the child's performance on at least one of the performance-based measures of vestibular function.

Discussion Related to the First Specific Aim

The first specific aim was to determine if parent responses can predict the child's abilities on performance-based vestibular measures. While the null hypothesis could not be rejected due to limitations in sample size and power, a meaningful relationship was discovered between parent reporting on the Balance and Motion subtest of the SPM and the child's performance on the Balance subtest of the BOT-2. This finding suggests that the Balance and Motion subtest of the SPM and the Balance subtest of the BOT-2 are measuring similar aspects of vestibular functioning. While the goal of administering different assessments during the evaluation process is to collect additional novel information, this slight redundancy provides evidence that parent proxy reporting is clinically important in describing their child's functional performance deficits. This finding is in contrast to Said et al.'s 2015 study which found that there was no relation between parent's perception of their children's balance and the test results of BOT-2 and mCTSIB.

Existing literature often looks at the vestibular and proprioceptive systems as a single functional system. In their 2014 article Parham and Su echo and expand on this idea in stating that "the vestibular and proprioceptive systems can be addressed as distinct systems but may also be interpreted as an integrated system" (Parham & Su, 2014, p.553). Therefore, the differences in correlations between the Body Awareness and Balance and Motion subtest scores of the SPM and the predicted outcomes on balance measures support the construct validity of the SPM. This finding shows that though the two systems form a single functional unit, the SPM is sensitive enough to capture differences in the two distinct sensory systems through examining the subtests' T-scores. This is important because findings from the SPM, along with other sources of data, help in intervention planning and can guide how these sensory differences will be addressed. As such, treatment activities can be designed to meet the specific needs of each sensory system. Consistent with the literature, parent reporting of proprioceptive processing was seen to correlate with the participants' performance-based assessment of balance at the item level of parent questionnaires. This topic is discussed further in the discussion of the third specific aim.

Cutoff levels. The second research question, embedded in specific aim 1, was to determine what cutoff ranges of the SPM maximized the true positive rate (i.e a sensitivity of at least 80%) while minimizing the false negative rate. We originally planned to examine this based on the proposed sample size of N =30. However, due to the limited sample size, there is insufficient data to support changing the existing cutoff. Presently the SPM uses T-scores at or below 60 to separate children with typical sensory processing from those who are likely experiencing sensory processing difficulties. The SPM uses a three-tiered classification system in describing the child's sensory processing. Children that have T-scores that are 1 standard deviation (SD) away from the mean are describe as being in the *Some Problems* range (T-score between 60-69). Children that are described by the SPM as having a *Definite Dysfunction* have T-scores ranging from 70-80. Cutoffs are important in proxy reporting measures because they are what provide interpretive value to parent responses. They help clinicians determine the need for further assessment, additional structured observations, and aid in prioritizing potential areas of intervention. Moreover, having an accurately tiered system of identifying and rating the severity of sensory dysfunction is important particularly in the absence of additional performance-based measures or limited space which is common in school settings. Further research with larger sample sizes is needed to determine the best cutoff levels for parent-report measures of sensory processing.

Based on the data that were collected in this study, the T-score of 60 was sensitive enough to capture 73.3% of the sample that scored Below Average on the Balance subtest of the BOT-2. This finding, though not statistically significant, is clinically important because it comes close to the targeted 80% sensitivity rate. While no definitive conclusions can be made about adjusting the cutoff based on this study's findings, interpreting SPM T-scores above 60, which falls in the *Some Problems* range as dysfunctional, is supported by the findings of this study, as clinical follow up is recommended for children who score in either the *Some problems* or *Definite dysfunction* range (Hansen & Jirikowic, 2013).

Discussion Related to the Second Specific Aim

The second specific aim of the study was to determine the constellation of direct and indirect measures that best predict functional and dysfunctional vestibular performance as measured by the Balance subtest of the BOT-2. With both direct and indirect measures entered into the regression, the SWAY was the only measure seen to have a predictive relationship with the Balance subtest of the BOT-2. A possible explanation of this is that both of these tests examine vestibular contributions to standing balance under vision occluded conditions. The SWAY Balance application uses accelerometers to measure postural control under four different conditions. These conditions vary the nature of the standing surface and measure postural control with the subject's eyes open and then with their eyes closed. Similarly, the Balance subtest of the BOT-2 evaluates trunk stability during static and dynamic balance tasks. It includes items that "requires the examinee's eyes to be closed, which assesses the extent to which an examinee depends on visual cues for maintaining balance" (Bruininks & Bruininks, 2005, p.6). Stated another way, the items that require the examinee to balance with their eyes closed examine vestibular contributions to balance while limiting the influence of the visual system.

In clinical settings, occupational therapists often have to use the best information available to them before moving forward to treatment planning and intervention. They have to employ sound clinical judgement when selecting assessment tools and methods. The results of this study suggest that the best predictor of dysfunctional vestibular processing as measured by the BOT-2 was the SWAY application. This is an interesting finding because, though the BOT-2 is a widely used assessment across settings, it can take up to or over an hour to administer the full assessment. The SWAY Balance application uses triaxial accelerometers housed in everyday mobile devices to quantify postural sway. It is administered and automatically scored in under 10 minutes. In instances when there is limited time, this finding may support the wider use of accessible technology as measures of sensory processing.

Discussion Related to the Third Specific Aim

The SPM and the BOT-2. The third and final specific aim of this study was to use an exploratory approach to describe the relationship between parent-report and performance-based measures of vestibular function. Interestingly, items on the Balance and Motion subtest of the SPM that directly asked about the child's balance (items 57 and 58) were found to have small to moderate (Field, 2011) correlations with performance on the Balance subtest of the BOT-2. More specifically, item 57 asks if the child has been observed to "Have good balance?" This item is purported to uncover vulnerabilities in postural control. Yet, responses on this item could also reveal issues related to under-responsivity to vestibular input as that would also impact one's balance. This item is of particular interest because it offers a direct comparison between parent proxy reporting of balance skills, as measured by the SPM, and the child's objective abilities as measured by the Balance subtest of the BOT-2. The moderate correlation found between this item and the Balance subtest scale score of the BOT-2, supports the claim that parent reporting is correlated with the child's performance on objective measures of vestibular functioning.

Of the six SPM items purported to examine postural control (items 57, 59, 60,64,66), three revealed moderate correlations with the Balance subtest of the BOT-2. This finding suggests that parents do a *fair* job of reporting observable vestibular signs. This finding contradicts Said et al.'s 2015 finding that parents often miss subtle vestibular signs or attribute them to behavior problems.

The Body Awareness subtest of the SPM examines the child's proprioceptive processing thorough 10 items aimed at uncovering sensory differences in perception and seeking. Moderate correlations were seen between items 48, 49, and 50 of the SPM and the Balance subtest of the BOT-2. These items are purported to uncover vulnerabilities in perception and seeking respectively. This finding may suggest that performance-based measures examining functional vestibular skills have stronger correlations with items that seek to uncover issues with sensory registration and active sensory seeking.

The SPM and PRN. PRN is the, often observable, sign associated with feeling dizzy and registering rotational movement input. The duration of PRN has been theorized to reflect functional balance skills and motor control. PRN that is shorter than average in duration is believed to be connected to impairments in postural control and motor performance (Mulligan, 2011). Item 61 on the Balance and Motion subtest of the SPM was of particular interest because it probes for under-responsivity evidenced by the child not getting dizzy when others usually do. While there were small correlations between this item and PRN, there were moderate correlations seen with several of the Body Awareness items (46, 48, and 49). Furthermore, PRN lasting longer than expected is believed to be associated with "a lack of higher cortical inhibition, or over-responsive to the rotational movement" (Mulligan, 2011, p.100). The moderate correlation between item 57 ("avoids balance activities") on the Balance and Motion subtest of the SPM and PRN CCW is emerging evidence of this claim. This finding should be interpreted with caution as the SPM manual acknowledges that "item responses are much less reliable than scale scores in terms of identifying problems" (Parham et al., 2007, p.28).

The SPM and SWAY Balance application. Overall, there were a greater number of moderate to large correlations seen between performance-based measures and items on the Body Awareness subtest of the SPM than between performance-based measures and the Balance and Motion subtest of the SPM. Item 50 on the Body Awareness subtest had the largest correlation (r=.60) of all of the items on the SPM with the SWAY Balance application, (eyes open condition) and a moderate correlation (r=.44) with the overall SWAY score. The relationship between postural control, as measured by the SWAY Balance application, and item 50 (Seem to exert too much pressure for the task such as walking heavily, slamming doors or pressing too hard when using pencils or crayons) may support what is commonly describe in the literature as the presence of co-occurring forms of SPD.

With the exception of modulation disorders, several forms of SPD are commonly known to co-occur (Miller & Fuller, 2014). Although item 50 is purported to uncover seeking (i.e. a modulation disorder), difficulty grading one's force is a hallmark sign of a proprioceptive discrimination disorder (Miller & Fuller, 2014). If this interpretation is applied to all of the items on the Body Awareness subtest probing the use of adequate force (items 49, 52, 55) a clear pattern is seen in how proprioceptive discrimination challenges correlate with postural disorders. Sensory discriminative disorders in particular are believed to rarely occur on their own (Miller & Fuller, 2014). Parent responses suggesting the presence of sensory discriminative challenges may signal the need for further testing to uncover co-occurring postural control difficulties. As noted in the SPM's instructional manual, therapist need to carefully consider responses and have specialized training in sensory processing in order to adequately interpret the SPM findings. Examining the patterns seen in parent responses with a wider interpretation and their overlap with patterns of dysfunction noted on performance-based measures can assist in accurately identifying various forms of SPD.

Further research exploring the predictive capacity of parent responses on the SWAY application is warranted. The predictive relationship between the SWAY application and parent responses could not be explored in this study because information regarding the normative ranges of postural sway as measured by the SWAY application is not yet available. As such, dysfunctional and functional classifications were not established and the SWAY results were not included in results or discussion of specific aim 1. The number and magnitude of the correlations (specific aim 3) seen between parent responses and the results of the SWAY application suggest that there may be a predictive relationship. When/if normative ranges of postural sway (as measured by this application) become available it would be helpful to repeat this study to examine this relationship.

Limitations. This study was limited by factors that impact the generalizability of the results. First, the study was limited by the nature of the sample. The small sample size limits the power to detect significant relationships and to extrapolate the findings back to the larger population. Additionally, the sample was made up of primarily (78%) male children and may not be an accurate reflection of females as females are known to outperform males in balance tasks involving single leg stances and standing heel-toe (Vedul-Kjelsås, 2013). Additionally, 71.1% of the sample was age 10 or over. Presently, there is lack of consensus on when an individual demonstrates mature postural sway. Some researchers suggest that a mature response isn't present until the child is between 10-14 (Nandi & Luxon, 2008), while others suggest that a mature response is present in children as young as seven or nine (Tjernstrom, et al., 2007). Measuring postural sway in children who have not yet developed a mature response can confound results by mislabeling normal amounts of variability as dysfunctional, in children who are still in an experimental phase. The study, the research team did not collect data on the caregiver providing the SPM-report data. Information such as the respondent's level of education and socioeconomic status may have been useful in better understanding the makeup of our sample and help identify possible confounding variables.

The parent-report measure used in the study also has limitations. Based on Miller's 2006 nosology, sensory processing disorder has three subtypes (sensory modulation disorders, sensory-based motor disorders, and sensory discrimination disorders). The SPM has a disproportionate number of items that probe for sensory modulation disorders. This imbalance may make the SPM less effective in identifying the other subtypes of sensory processing disorders. Additionally, the SPM does not have an index that quantifies reporter bias. Other parent-report measures used in and outside of the field of occupational therapy have indices of rater bias, inconsistency, and negativity. Subjective information and proxy reporting is always vulnerable to bias. Not including indices of these potential areas of bias introduce an uncontrolled amount of variance to the study.

Conclusion. We hypothesized that the information collected from the SPM could be used to predict the child's performance on at least one of the performance-based measures of vestibular function. We found a meaningful relationship between the BAL T-score on the SPM and the child's performance on the Balance subtest of the BOT-2. The BAL T-score was determined to be a *fairly* useful predictor of the child's performance on the Balance subtest of the BOT-2 while the BOD T-score was found not to be a useful predictor of the child's objective performance on the BOT-2 or any of the direct measures of vestibular function. Furthermore, we found that the SPM's T-score cutoff of 60 had an accuracy of 73.3% which was close to our targeted 80%. Next, after entering in all the parent-report data and performance-based data into an adjusted model, the SWAY Balance variable was found to be the only assessment related to predicting the child's performance on the Balance subtest of the BOT-2. Lastly, in the exploratory analysis we found that, there were *moderate* correlations seen at the subtest and item level when examining the relationship between parent responses on the BAL subtest and the performance-based measures and *moderate* to *large* correlations observed between item level parent responses on the BOD subtest and the performance-based measures.

Currently, there is a significant amount of variability in the literature and the field of occupational therapy about how to identify sensory dysfunction. In clinical practice and in research studies, a single parent-report measure indicating differences in sensory processing has been used to identify sensory dysfunction (Ahn et al., 2004; White et al., 2007). When used alone, parent questionnaires such as the SPM act as *screening* tools (Parham et al., 2007). It is recommended that evaluators collect information from a wide variety of sources (e.g., standardized rating scales, clinical observations, caregiver interviews, medical record reviews, and possibly performance-based measures (Parham et al., 2007) before moving forward to intervention planning. There is not yet a set standard for the level or type of data collected needed to determine SPD or more specifically vestibular forms of SPD. The results of this study show that there is slight overlap between the subjective information that is collected from proxy reporting measures and the objective information gathered from performance-based assessment methods.

This agreement may provide support for the field adopting a standard of practice of identifying and assessing sensory processing through the required use of both subjective and objective measures. Identifying sensory processing disorder through both subjective and objective assessment methods may help with SPD subtype profiling and assist in controlling the variability in future research on SPD. Furthermore, because there is evidence of agreement between assessment methods and not an overwhelming redundancy of information, the results of this study suggest that parent-report measures may also be capturing unique aspects of functional sensory processing disorders not gained from performance-based measures.

Overall, parent questionnaires are valued measurement tools because they provide qualitative information providing insight into possible areas of occupational dysfunction that may not otherwise be able to be collected from the child. Parent-report measures are useful tools because they are easy to administer, summarize the child's pattern of performance overtime, and require little to no equipment. They are administered at the beginning of the occupational therapy process and set the foundation for hypotheses to be created and later tested. Parent questionnaires, however, are not sensitive enough nor intended to be used as repeated measures to capture functional improvements resulting from targeted sensory intervention.

Performance-based measures are intended to measure progress overtime. While there is evidence to suggest that PRN may not be responsive to therapy, one's postural sway is modifiable overtime with intervention. As noted, before, the full test battery of comprehensive performance-based measures of sensory processing available in the field today (e.g., SIPT) are rarely administered. Yet, certain portions of these assessments, such as measures of PRN and postural sway, are still commonly used in clinical practice today. These clinical findings are usually combined with the results of standardized performance-based assessments of motor proficiency and used to infer underlying sensory processing. The results of this study support this practice.

This combined method of assessing vestibular function is used both inside and outside of the field of occupational therapy. Occupational therapists often rely on performance-based measures that use clinician observation rather than technology-based measures. This is because technology-based assessments, commonly used in other disciplines, are large, costly, and do not provide information on functional deficits. The predictive relationship and large correlation between parent responses and the SWAY Balance application provide support for using accessible technology in measuring sensory skills. The field should consider including accessible modes of technology-assisted assessment in moving the profession forward.

The findings of this study support the relationship between parent reporting and their child's performance on objective measures; more specifically technology-assisted measures. It is important to repeat this study as revised parent-report measures become available because to date, parent reporting is generally only used to capture baseline functioning. Further research is needed to explore the role that technology-assisted assessment of sensory processing has in quantifying baseline sensory processing skills and tracking the response to intervention overtime.

References

Ahn, R. R., Miller, L. J., Milberger, S., & McIntosh, D. N. (2004). Prevalence of parents' perceptions of sensory processing disorders among kindergarten children. *American Journal of Occupational Therapy, 58*, 287–293.

Amick, R. Z., Jansen, S. D., Chaparro, A., Hakansson, N. A., Patterson, J. A., & Jorgensen, M. J. (2015). Comparison of the SWAY Balance Mobile Application to the Abbreviated Balance Error Scoring System. *Athletic Training & Sports Health Care,7*(3), 89-96. doi:10.3928/19425864-20150422-04

Anderson, S., Gatens, D., Glatts, C., & Russo, S. (2017). Normative Data set of SWAY Balance Mobile Assessments in Pediatric Athletes. *Clinical Journal of Sports Medicine,*1-8. doi:10.1097/JSM.0000000000000545

Ayres, A. (1978). Learning Disabilities and the vestibular System. *Journal of Learning Disabilities, 11(1), 30-41*

Ayres, A., & Robbins, J. (1979). *Sensory integration and the child*. Los Angeles, Calif.: Western Psychological Services.

Baloh, R. W., Kerber, K. A., & Honrubia, V. (2011). *Clinical neurophysiology of the vestibular system*. New York: Oxford University Press.

Barmack N.H., Yakhnitsa V. (2013) Vestibulocerebellar Connections. In: Manto M., Schmahmann J.D., Rossi F., Gruol D.L., Koibuchi N. (eds) *Handbook of the Cerebellum and Cerebellar Disorders*. Springer, Dordrecht

Basta, D., Todt, I., Scherer, H., Clarke, A., Ernst, A. (2005). Postural control in otolith disorders. *Human movement Science, 24, 268-279.* Doi: 10.1016/jhumov.2005.04.002

Bayley, N. (2006). *Bayley Scales of Infant and Toddler Development–Third Edition:* Administration manual. San Antonio, TX: Harcourt Assessment

Ben-Sasson, A., Carter, A.S., & Briggs Gowan, M.J. (2009). Sensory over-responsivity in elementary school: prevalence and social-emotional correlates. *Journal of Abnormal Child Psychology, 37*,705-716.

Bear, M. F., Connors, B. W., & Paradiso, M. A. (2016). *Neuroscience: exploring the brain*. Wolters Kluwer.

Bodison S. C. (2015). Developmental Dyspraxia and the Play Skills of Children With Autism. *The American journal of occupational therapy : official publication of the American Occupational Therapy Association*, 69(5), 6905185060. https://doi.org/10.5014/ajot.2015.017954

Broussard, D. M. (2013). *The cerebellum: learning movement, language, and social skills*. Ames, Iowa: Wiley Blackwell.

Bronstein, A.M, Pavlou, M. (2013). Balance. In M. P Barnes & D. C Good (Ed.), *Handbook of Clinical Neurology* (pp 189-208). United Kingdom: Elsevier

Brown, T., Morrison, I. C., & Stagnitti, K. (2010). The Reliability of Two Sensory Processing Scales Used with School-Age Children: Comparing the Response Consistency of Mothers, Fathers, and Classroom Teachers Rating the Same Child. *Journal of Occupational Therapy, Schools, & Early Intervention,3*(4), 331-347. doi:10.1080/19411243.2010.541775

Bruininks, R., & Bruininks, B. (2005). Bruininks-Osteretsky Test of Motor Proficiency, 2nd Ed- Manual. Circle Pines, MN: AGS Publishing.

Bundy, A., Lane, S., & Murray, E. (2002). *Sensory integration: Theory and practice* (2nd ed.). Philadelphia: F.A. Davis.

Canalis, R. F., & Lambert, P. R. (2000). *The ear: comprehensive otology*. Philadelphia: Lippincott Williams, & Wilkins.

Carey, L. M., Lamp, G., & Turville, M. (2016). The State-of-the-Science on Somatosensory Function and Its Impact on Daily Life in Adults and Older Adults, and Following Stroke. *OTJR: Occupation, Participation and Health,36*(2). doi:10.1177/1539449216643941

Carter, J. V., Pan, J., Rai, S. N., & Galandiuk, S. (2016). ROC-ing along: Evaluation and interpretation of receiver operating characteristic curves. *Surgery*, *159*(6), 1638–1645. doi.org/10.1016/j.surg.2015.12.029

Cattaneo, D., Regola, A., & Meotti, M. (2006). Validity of six balance disorders scales in persons with multiple sclerosis. *Disability and Rehabilitation*, *28*(12), 789-795. doi:10.1080/09638280500404289

Chu, V. W. (2016). Assessing Proprioception in Children: A Review. *Journal of Motor Behavior,49*(4), 458-466. doi:10.1080/00222895.2016.1241744

Cullen, K. E. (2012). The vestibular system: multimodal integration and encoding of self-motion for motor control. *Trends in Neurosciences,35*(3), 185-196. doi:10.1016/j.tins.2011.12.001.

Cushing, S., Levi, J., & O'Reilly, R. (2013). History and Physical Examination of the child with a Balance Disorder. In *Manual of Pediatric Balance Disorders* (pp. 36-69). Plural Publishing Inc.

Deitz, J. C., Kartin, D., & Kopp, K. (2007). Review of the Bruininks-Oseretsky Test of Motor Proficiency, Second Edition (BOT-2). *Physical & Occupational Therapy In Pediatrics, 27*(4), 87-102. doi:10.1080/j006v27n04_06

Dunn, W. (2014). *Sensory Profile 2 manual.* San Antonio, TX: Pearson.

Dieterich, M., & Brandt, T. (2015). The bilateral central vestibular system: Its pathways, functions, and disorders. *Ann. N.Y. Acad. Sci. Annals of the New York Academy of Sciences, 1343*(1), 10-26. doi:10.1111/nyas.12585

Field, A. P. (2011). *Discovering statistics using SPSS*. London: SAGE.

Folio, R., & Fewell, R. (2000). *Peabody Developmental Motor Scales* (2nd ed.). Austin, TX: Pro-Ed, Inc.

Gabriel, L. (2001). *Developmental changes in postural stability in children* (Doctoral dissertation). Retrieved from UMI. (Accession No. 3013054**)**

Gurvich, C., Maller, J. J., Lithgow, B., Haghgooie, S., & Kulkarni, J. (2013). Vestibular insights into cognition and psychiatry. *Brain Research, 1537*, 244-259. doi:10.1016/j.brainres.2013.08.058

Gutman, S. A. (2008). Quick reference neuroscience (2nd ed.). Thorofare, NJ: SLACK.

Hanes, D.A., McCollum, G., (2006) Cognitive-vestibular interactions: A review of patient difficulties and possible mechanisms. *Journal of Vestibular Research*, *16*, 75-91.

Hansen, K. D., & Jirikowic, T. (2013). A comparison of the sensory profile and sensory processing measure home form for children with fetal alcohol spectrum disorders. *Physical & Occupational Therapy in Pediatrics*, *33*(4), 440-452. doi:10.3109/01942638.2013.791914

Hegeman, J., Shapkova, E.Y., Honegger, F., Allum, J.H. (2007). Effect of age and Height on trunk sway during stance and gait. *Journal of Vestibular Research, 17*, 75-87.

Johnson-Ecker, C. L., & Parham, L. D. (2000). The Evaluation of Sensory Processing: A Validity Study Using Contrasting Groups. *American Journal of Occupational Therap*y, *54*(5), 494-503. doi:10.5014/ajot.54.5.494

Jirikowic, T., McCoy, S., Lubetzky-Vilnai, A., Price, R., Ciol, M., Kartin, D., . . . Astley, S. (2013, September 6). Sensory control of balance: A comparison of children with fetal alcohol spectrum disorder to children with typical development. *Journal of Population Therapeutics and Clinical Pharmacology*, 20(3), 212-228. Retrieved November 11, 2016.

Juhola, M., Aalto, H., Jutila, T., & Hirvonen, T. P. (2010). Signal Analysis of Three-dimensional Nystagmus for Otoneurological Investigations. *Annals of Biomedical Engineering*, *39*(3), 973–982. https://doi.org/10.1007/s10439-010-0211-3

Kahn, S., & Chang, R. (2013). Anatomy of the Vestibular system: A review. *NeuroRehabilitation,*

Kennedy,J., Brown, T., Chien , C. (2012). Motor Skill Assessment of Children: Is There an Association Between Performance-Based, Child-Report, and Parent-Report Measures of Children's Motor Skills? *Physical & Occupational Therapy In Pediatrics, 32*.

Koester, A. C., Mailloux, Z., Coleman, G. G., Mori, A. B., Paul, S. M., Blanche, E., . . . Cermak, S. A. (2014). Sensory integration functions of children with cochlear implants. *American Journal of Occupational Therapy*, *68*, 562– 569. http://dx.doi.org/10.5014/ajot.2014.012187

Lalor, A., Brown, T., & Murdolo, Y. (2016, September 14). Relationship between children's performance-based motor skills and child, parent, and teacher perceptions of children's motor abilities using self/informant-report questionnaires. *Australian Occupational Therapy Journal*, *63*(2), 105-116. doi:10.1111/1440-1630.12253

Mailloux, Z., Mulligan, S., Roley, S. S., Blanche, E., Cermak, S., Coleman, G. G., et al. (2011). Verification and clarification of patterns of sensory integrative dysfunction. *American Journal of Occupational Therapy*, *65*, 143–151. doi: 10.5014/ajot.2011.000752

Mast, F. W., Preuss, N., Hartmann, M., & Grabherr, L. (2014). Spatial cognition, body representation and affective processes: The role of vestibular information beyond ocular reflexes and control of posture. *Frontiers in Integrative Neuroscience, 8*. doi:10.3389/fnint.2014.00044

May-Benson, T.A., & Koomar, J.A. (2007). Identifying gravitational insecurity in children : A pilot study. *American Journal of Occupational Therapy.* 61.142-147

McLean, B., Taylor, S., Blair, E., Valentine, J., Carey, L., & Elliott, C. (2017). Somatosensory discrimination intervention improves body position sense and motor performance in children with hemiplegic cerebral palsy. *American Journal of Occupational Therapy*, *71*, 7103190060. https://doi.org/10.5014/ajot.2016.024968

Metz, C. E. (1978). Basic principles of ROC analysis. *Seminars in Nuclear Medicine*, *8*(4), 283-298. doi:10.1016/s0001-2998(78)80014-2

Miller, L. J. (2006). *Miller Function & Participation Scales Examiner's Manual*. San Antonio, TX: Harcourt Assessment.

Miller, L. J., & Fuller, D. A. (2014). What is Sensory processing Disorder? In *Sensational kids: Hope and help for children with sensory processing disorder (SPD)* (pp. 5-18). New York, NY: Penguin Group.

Miller, L. J., Anzalone, M. E., Lane, S. J., Cermak, S. A., & Osten, E. T. (2007). Concept Evolution in Sensory Integration: A Proposed Nosology for Diagnosis. *American Journal of Occupational Therapy*,*61*(2), 135-140. doi:10.5014/ajot.61.2.135

Miller-Kuhaneck, H., Henry, D. A., Glennon, T. J., & Mu, K. (2007). Development of the Sensory Processing Measure-School: initial studies of reliability and validity. *The American journal of occupational therapy: official publication of the American Occupational Therapy Association*, *61*(2), 170–175. https://doi.org/10.5014/ajot.61.2.170

Morlet, S. (2013). Physiology and Maturation of Balance Disorder. In *Manual of Pediatric Balance Disorders* (pp. 36-69). Plural Publishing Inc.

Mulligan, S. (2011) Validity of the post-Rotary nystagmus Test for measuring vestibular Function. *OTJR: Occupation, Participation and Health, 31* (2*)*. Doi**:** 10.3928/15394492-20100823-02

Nandi, R., Luxon, L., (2008). Development and assessment of the vestibular system. *International Journal of Audiology 47*, 566-577. Doi: 10.1080/1492020802324540

Niklasson, M., Niklasson, I., & Norlander, T. (2009). *Sensorimotor Therapy: Using Stereotypic Movements And Vestibular Stimulation To Increase Sensorimotor Proficiency Of Children With Attentional And Motor Difficulties 1,2*. Perceptual and Motor Skills, *108*, 643-669

Parham, L.D., Ecker, C., Miller Kuhaneck, H., Henry, D.A., & Glennon, T.J. (2007).*Sensory Processing Measure (SPM)*: [Manual]. Torrance, CA: Western Psychological Services

Parham, L.D.,& Ecker, C. (2007). *Sensory Processing Measure (SPM) Home Form*. Los Angeles: Western Psychological Services.

Patterson, J.A., Amick, R.Z., Thummar, T., Rogers, M.E. (2014). Validation of measures from the smartphone SWAY Balance Application: a Pilot Study. *The International Journal of Sports Physical Therapy, 9(2), 135-139*

Pienaar, A. E., Botha, J., Vermeulen, C., & Ballack, M. (2007). A review of the interrelationship between vestibular dysfunction, motor and learning disabilities and the rehabilitation thereof. *South African Journal for Research in Sport, Physical Education and Recreation, 29*(1). doi:10.4314/sajrs.v29i1.25960

Reeves, G., & Cermak, S. (2002). Disorders of praxis. In Sensory Integration Theory and Practice (2nd ed., pp. 71-95). Philadelphia, PA: F,A. Davis.

Rine, R.W. & Wiener-Vacher, S. (2013). Evaluation and treatment of vestibular dysfunction in children. *NeuroRehabilitation*, *32*(3), 507-18. doi: 10.3233/NRE-130873.

Reinert, S. S., Jackson, K., & Bigelow, K. (2014). Using Posturography to Examine the Immediate Effects of Vestibular Therapy for Children with Autism Spectrum Disorders: A Feasibility Study. *Physical & Occupational Therapy In Pediatrics*, *35*(4), 365-380. doi:10.3109/01942638.2014.975313

Said, E. A., Ahmed, M. K., & Mohamed, E. S. (2015). Role of vestibular testing in deciding treatment strategies for children with otitis media with effusion. *Egyptian Journal of Ear, Nose, Throat and Allied Sciences*, *16*(2), 151–159. https://doi.org/10.1016/j.ejenta.2015.05.003

Schaaf, R. C., Dumont, R. L., Arbesman, M., & May-Benson, T. A. (2018). Efficacy of Occupational Therapy Using Ayres Sensory Integration®: A Systematic Review. *American Journal of Occupational Therapy*,*72*(1). doi:10.5014/ajot.2018.028431

Shinder, M. E., & Taube, J.S. (2009). Differentiating ascending vestibular pathways to the cortex involved in spatial cognition. *Journal of Vestibular Research, 20, 3-23.* Doi:10.3233/VES-2010-0344

(SIPT) Sensory Integration and Praxis Tests. (2017). Retrieved December 09, 2017, from https://www.wpspublish.com/store/p/2971/sipt-sensory-integration-and-praxis-tests

Strupp, M., Fischer, C., Han., L, Bayer, O. (2014). The takeaway Frenzel goggles. *American Academy of Neurology, (83),* 1241-1245.

Su, W., Lin, C., & Chang, S. (2015). A study of safety and tolerability of rotatory vestibular input for preschool children. *Neuropsychiatric Disease and Treatment,*41-49. doi:10.2147/ndt.s76747

Tabachnick, B., & Fidell, L. (2013). *Using Multivariate Statistics* (6th ed.). Upper saddle River, NJ: Pearson Education

Tjernstrom, F., Oredsson, J., Magnusson, M. (2007). A "wait and learn" strategy of postural control learning in children? *Journal of vestibular Research, 16, 257-264.*

Vedul-Kjelsås, V., Stensdotter, A., & Sigmundsson, H. (2013). Motor Competence in 11-Year-Old Boys and Girls. *Scandinavian Journal of Educational Research, 57*(5), 561-570. doi:doi.org/10.1080/00313831.2012.732603

White, B.P, Mulligan S, Merrill K, & Wright J. (2007). An examination of the relationships between motor and process skills and scores on the Sensory Profile. *American Journal of Occupational Therapy,* 61(2), 154–160.

Williams, M. S., & Shellenberger, S. (1996). *How Does Your Engine Run?: a Leaders Guide to The Alert Program for Self-Regulation. Albuquerque: Therapy Works, Inc.*

Wilson, B., Kaplan, B., Pollock, N., & Law, M. (2000). *Clinical Observation of Motor and Postural Skills: Administration and scoring manual* (2^{nd} ed.). Framingham, MA: Therapro, Inc.

Appendix A

Screening Intake Form

Child Name: _______________________
Child's DOB: ________________________
Chronological Age: _________
Medical Diagnosis (optional):_________________
Parent's Name: ___________________
Phone Number: ____________________
Email address: ___________________

Medication taken

Does (is) your child have:

	YES	NO
Between the ages of 5-12		
History of cancer or brain tumor		
History of Traumatic brain Injury		
Musculoskeletal disorder (including moderate to severe lordosis, scoliosis, or kyphosis)		
Leg length discrepancies		
vestibular integration challenges identified by a licensed clinician or suspected challenges per parent-report		
Meet the diagnostic criteria for ICD 10 code R27.8 (lack of coordination)		
receiving OT to address sensory-motor differences for 12 sessions or less		
Normal/ corrected to normal vision		
In overall good heath? (i.e. no active sinus infections, ear infections, colds)		
Able to attend to and follow simple verbal instructions (i.e. "stand still for 10 seconds" and "sit down")		
No history or active seizure disorder		
functional use and/or range of motion of arms or legs within functional limits		
Hearing loss or auditory disorder (i.e. conductive or sensorineural hearing loss, ear infection, tinnitus)		
Eye problems (i.e. Strabismus, nystagmus, diplopia)		
Recent evaluation/ re-evaluation using the BOT-2 in the past 7 days		
prone to motion sickness		

Verbal consent given? Yes □ No □

Testing date: __________________

Appendix B

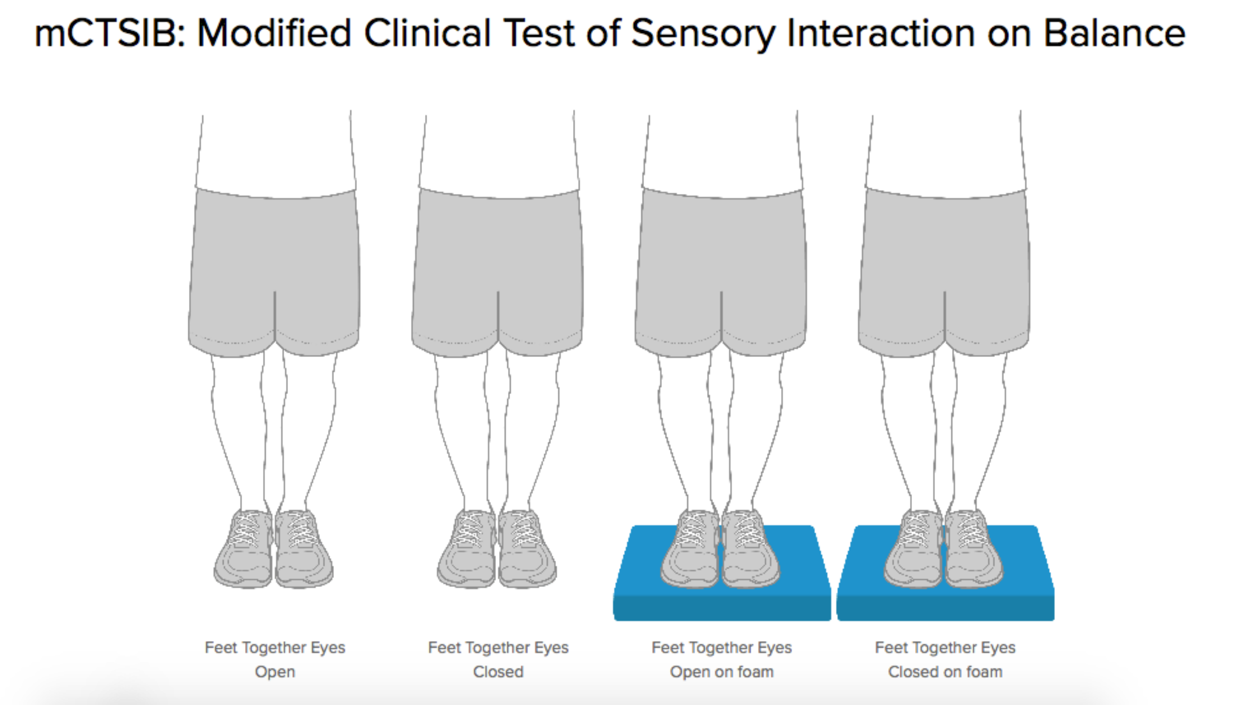

mCTSIB: Modified Clinical Test of Sensory Interaction on Balance
Feet Together Eyes Open
Feet Together Eyes Closed
Feet Together Eyes Open on foam
Feet Together Eyes Closed on foam

Table B1: *Correlations Between Parent-report and Direct Measures*

		BOT Scale Score	PRN CW	PRN CCW	SWAY	SWAY EO	SWAY ECF
BAL T-score	Spearman Rho	-0.36	-0.09	0.22	-0.23	-0.17	-0.31
	Sig. (2 tailed)	0.07	0.67	0.29	0.25	0.41	0.12
	N	27	25	24	27	27	27
BAL item 56 Seem excessively fearful of movement, such as going up and down stairs	Spearman Rho	-0.15	-0.06	0.24	-0.28	-0.43*	-0.03
	Sig. (2 tailed)	0.47	0.79	0.27	0.16	0.03	0.88
	N	27	25	24	27	27	27
BAL item 57 Have good balance?	Spearman Rho	0.35	0.08	-0.18	0.26	0.32	0.15
	Sig. (2 tailed)	0.07	0.69	0.40	0.20	0.11	0.44
	N	27	25	24	27	27	27
BAL item 58 Avoid balance activities?	Spearman Rho	-0.27	0.26	0.46*	-0.24	-0.31	0.10
	Sig. (2 tailed)	0.17	0.20	0.02	0.23	0.12	0.63
	N	27	25	24	27	27	27
BAL item 59 Fall out of chair when shifting his or her weight?	Spearman Rho	0.14	-0.37	0.01	0.06	0.16	-0.01
	Sig. (2 tailed)	0.47	0.07	0.98	0.78	0.43	0.94
	N	27	25	24	27	27	27
BAL item 60 Fail to catch himself or herself when falling	Spearman Rho	-0.06	0.04	0.06	.05	.16	-.08
	Sig. (2 tailed)	0.77	0.84	0.78	0.82	0.43	0.68
	N	27	25	24	27	27	27
BAL item 61 Seem not to get dizzy when others usually do?	Spearman Rho	0.17	-0.25	-0.11	0.04	0.09	-0.13
	Sig. (2 tailed)	0.40	0.23	0.61	0.83	0.64	0.51
	N	27	25	24	27	27	27
BAL item 62 Spin and whirl his or her body more than other children?	Spearman Rho	0.14	-0.48*	-0.17	0.32	0.29	0.21
	Sig. (2 tailed)	0.49	0.02	0.43	0.11	0.15	0.29
	N	27	25	24	27	27	27
BAL item 63 Spin and whirl his or her body more than other children?	Spearman Rho	-0.18	0.24	-0.28	0.23	-0.28	-0.17
	Sig. (2 tailed)	0.37	0.24	0.18	0.26	0.16	0.41
	N	27	25	24	27	27	27
BAL item 64 Show poor coordination and appear clumsy	Spearman Rho	-0.34	-0.34	-0.12	0.07	0.13	-0.08
	Sig. (2 tailed)	0.80	0.58	0.34	0.73	0.51	0.68
	N	27	25	24	27	27	27
BAL item 65 Seem afraid of riding in elevators or on escalators	Spearman Rho	-0.16	0.03	0.09	-0.13	-0.08	0.06
	Sig. (2 tailed)	0.42	0.88	0.69	0.51	0.68	0.75
	N	27	25	24	27	27	27

BAL item 66 Lean on other people or furniture	Spearman Rho	-0.31	0.06	0.10	-0.17	-0.19	-0.14
	Sig. (2 tailed)	0.12	0.77	0.63	0.39	0.35	0.48
	N	27	25	24	27	27	27
BOD T-score	Spearman Rho	-0.16	0.19	0.23	-0.06	0.02	-0.10
	Sig. (2 tailed)	0.42	0.36	0.27	0.75	0.94	0.61
	N	27	25	24	27	27	27
BOD item 46 Grasp object objects (such as a pencil or spoon) so tightly that it is difficult to use the object?	Spearman Rho	0.15	0.31	0.39	-0.02	0.13	-0.12
	Sig. (2 tailed)	0.46	0.14	0.06	0.91	0.51	0.56
	N	27	25	24	27	27	27
BOD item 47 Seem driven to seek activities such as pushing, pulling dragging, lifting, and jumping	Spearman Rho	0.07	-0.00	0.01	0.03	0.17	-0.17
	Sig. (2 tailed)	0.73	0.99	0.98	0.88	0.41	0.40
	N	27	25	24			
BOD item 48 Seem unsure of how far to raise and lower the body during movement such as siting down or stepping over an object?	Spearman Rho	-0.39*	0.20	0.32	-0.41*	-0.33	-0.34
	Sig. (2 tailed)	0.05	0.33	0.13	0.04	0.10	0.08
	N	27	25	24	27	27	27
BOD item 49 Grasp objects (such as a pencil or spoon) so loosely that is it difficult to use the object?	Spearman Rho	-0.42	0.38	0.39	-0.28	-0.34	-0.04
	Sig. (2 tailed)	0.03	0.06	0.06	0.16	0.08	0.85
	N	27	25	24	27	27	27
BOD item 50 Seem to exert too much pressure for the task such as walking heavily, slamming doors or pressing too hard when using pencils or crayons?	Spearman Rho	0.31	0.20	0.17	0.44*	0.60**	0.23
	Sig. (2 tailed)	0.12	0.35	0.42	0.02	0.00	0.26
	N	27	25	24	27		27
BOD item 52 Tends to pet animals with too much force?	Spearman Rho	0.30	0.07	-0.08	0.07	0.20	-0.02
	Sig. (2 tailed)	0.14	0.75	0.70	0.71	0.33	0.93
	N	27	25	24	27	27	27
BOD item 55 Breaks things from pressing or pushing too hard on them?	Spearman Rho	-0.07	-0.25	-0.13	0.02	0.34	-0.19
	Sig. (2 tailed)	0.72	0.23	0.55	0.91	0.09	0.34
	N	27	27	24	27	27	27

Note: BAL T-score: Balance subtest of Sensory Processing Measure; BAL item#= item response in Balance and Motion subtest of Sensory Processing Measure; BOD T scores: Body Awareness subtest of the Sensory Processing Measure; BOD item#= item response in Body Awareness subtest of Sensory Processing Measure PRN CW: clockwise post-rotary nystagmus; PRN CCW: counter clockwise post- rotary nystagmus; BOT-2: Bruininks-Oseretsky Test of Motor Proficiency- Balance subtest; SWAY= overall SWAY score; SWAY EO= SWAY eyes open; SWAY ECF= SWAY subtest with eyes closed standing on foam
*p<.05, **p<.01 (2-tailed)

Vita

EDUCATION

Health Related Sciences (PhD), Virginia Commonwealth University, Richmond, VA, 2020

Occupational Therapy (MSOT), Howard University, Washington, DC, 2011

Hearing and Speech Sciences (B.S), University of Maryland, College Park, Maryland, 2009

HONORS AND AWARDS

Phi Theta Epsilon Honor Society, Howard University, 2011

PROFESSIONAL MEMBERSHIPS/ COMMUNITY SERVICE

- American Occupational Therapy Association (Member), Present
- Space of Her Own (Mentor), Present
- Alive, (Volunteer), Present
- Carpenter Shelter (Volunteer), Present
- Rebuilding Together, 2017

TEACHING EXPERIENCE

- **Howard University Adjunct Faculty (2020-Present)**
  Facilitated in-person and virtual laboratory experiences; provided timely feedback to the students; facilitated Blackboard discussions, and created video course content for student learning in remote settings.

- **St. Catherine University Didactic Course Instructor (2020)**
  Instructed students in Pediatric I and Pediatrics II coursework. Explained concepts such as sensory integration, motor milestones, therapeutic positioning, etc.; facilitated asynchronous and synchronous discussions on course material, and provided timely feedback on assignments.

- **St. Catherine University Clinical Lab instructor (2019)**
  Led adult students though hands on learning experiences and explained clinical aspects of occupational therapy.

- **St Catherine University Fieldwork Instructor (2019)**
  Led multi-day fieldwork experiences for groups of OTA students. Directed student observation and explained the role of an occupational therapist in various settings during field work placements. Evaluated adult students on areas of professionalism, proficiency with course content, safety, and communication skills.

RESEARCH INTERESTS

Vestibular Dysfunction, Sensory Processing, Human Development, Motor Learning

SCHOLARLY ACTIVITIES

- Presentation, *The Role of Occupational Therapy*, KIPP DC Public Charter School, May 2020.
- Keynote Speaker, Pi Theta Epsilon Honor Society Induction Ceremony, Howard University, February, 2016.