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Multidimenstional Balance in Youth with Visual Impairments

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MULTIDIMENSTIONAL BALANCE IN YOUTH WITH VISUAL IMPAIRMENTS

by

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DEDICATION

To borrow from Reinhold Niebuhr’s playful dedication to his wife and children found within *The Nature and Destiny of Man*: To my wife Kelly “who frequently interrupted me in the writing of these pages.” I would not have had it any other way. Your unconditional love and support have been (and will continue to be) my saving grace.

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ABSTRACT

This dissertation consists of three studies which examined multidimensional balance in youth (≤ 21 years; Individuals with Disabilities Education Act, 2004) with visual impairments (VIs) using the Brief-Balance Evaluation Systems Test (Brief-BESTest). These studies have the potential to inform (adapted) physical education curricula and therapeutic/rehabilitative practices by providing novel understandings of balance performance in youth with VIs. If identified as a meaningful mechanism of action, the assessment and development of multidimensional balance in youth with VIs should be given elevated status by practitioners. Thus, the purpose of this dissertation was to investigate multidimensional balance in youth with VIs.

The purpose of Study 1 was to examine the construct and convergent validity of the Brief-BESTest scores in youth with VIs. One-hundred and one youth with VIs (n_{boys} = 57) aged 8.7 to 20.4 years (M = 13.91 ± 2.82) completed the Brief-BESTest, the anterior reach of the Lower Quarter Y-Balance Test, the 360-degree turn test, inertial postural sway during quiet bipedal stance, and the Activities-specific Balance Confidence Scale. Favorable results were uncovered for the internal consistently reliability (ω = .87) and Spearman inter-item correlations (.18 to .73) for Brief-BESTest item scores. A one-factor minimum residual exploratory factor analysis using oblimin rotation was supported. Using seven of the eight Brief-BESTest (i.e., one bilaterally scored item [reactive postural response to the left side] was removed due to minor multicollinearity issues) and mean and variance-adjusted weighted least squares confirmatory factor analyses, a two-

factor (i.e., static and dynamic balance) model was accepted based on measures of global and local fit. Using Spearman correlations, the Brief-BESTest total scores significantly correlated (i.e., converged) with all other balance assessment total scores (-.36 to .67). These results confirmed that Brief-BESTest scores had satisfactory construct and convergent validity in youth with VIs.

The purpose of Study 2 was to compare Brief-BESTest scores between youth with and without VIs. Two-hundred and eighty-seven youth with (n_{VI} = 129) and without VIs aged 8.7 to 20.4 years (M = 13.80 ± 2.32) completed the Brief-BESTest. A one-way analysis of variance (ANOVA) suggested youth with VIs had lower total Brief-BESTest scores (F = 225.13, p < .001, ω^2 = .44). Concerning the eight individual Brief-BESTest items, a one-way multivariate analysis of variance (MANOVA) was statistically significant (F = 43.07, p < .001, V = .55). Games-Howell *post hoc* analyses highlighted significantly impaired balance performance in youth with VIs for all Brief-BESTest items except for the sensory orientation task (i.e., static bipedal stance on foam with eyes closed). The largest effect sizes (ω^2) were for the anticipatory postural adjustment (i.e., right [.46] and left [.50] single leg stances; static balance) and biomechanical constraint (i.e., hip/trunk lateral strength [.26]; static balance) systems. After subsetting the youth with VIs within the sample, an analysis of covariance (ANCOVA) suggested that both degree of vision (F = 3.60, p = .016, ω^2 = .04) and the presence of a comorbidity (F = 51.21, p < .001, ω^2 = .27) were significant explanatory variables for total Brief-BESTest scores in youth with VIs. These results suggested that youth with VIs are likely to have impaired balance performance in both static and dynamic tasks (i.e., five out of six balance systems) when compared to peers without VIs. Balance impairments in youth with VIs are likely due to environmental and/or sociological constraints and can likely be improved with targeted intervention. Practitioners should acknowledge and consider the roles of vision level and/or the presence of a comorbidity when investigating multidimensional balance performance in youth with VIs.

The purpose of Study 3 was to investigate associations between Brief-BESTest and the Test of Gross Motor Development-3 (TGMD-3) locomotor subscale scores in youth with VIs. Ninety-six youth with VIs (n_{boys} = 52) aged 8.7 to 19.0 years (M = 12.98 ± 2.28) completed the Brief-BESTest and the TGMD-3 locomotor subscale. The zero-order Spearman correlation between Brief-BESTest and TGMD-3 locomotor subscale total scores was strong (ρ = .60, p < .001, 95% CI = .46 to .72). Vision level and the presence of a comorbidity were identified as confounding variables. A second-order partial Spearman correlation simultaneously controlling for the presence of a comorbidity and vision level was .42 (p < .001, 95% CI = .24 to .57). These data suggest that a significant monotonic association existed between global multidimensional balance and locomotor performance in youth with VIs (i.e., total scores). Concerning individual Brief-BESTest and TGMD-3 item relationships, results were mixed. Zero-order Spearman correlations between individual Brief-BESTest and TGMD-3 locomotor subscale items ranged from -.09 to .55. It could be suggested that certain balance systems may play a role in (e.g., constrain) certain locomotor skills in youth with VIs. Practitioners should acknowledge that specific balance systems may play a more prominent or withdrawn role in different locomotor skills (i.e., inter-task specificity). Thus, practitioners should actively develop multidimensional balance skills in youth with VIs in tandem with other motor skills.

These data have the potential to significantly impact balance assessment which could in turn influence (adapted) physical education curricula (e.g., Individualized Education Program goals) or therapeutic/rehabilitative decisions for youth with VIs. Information gleaned from this dissertation suggests that multidimensional balance could be posited as a significant (yet modifiable) mechanism of action which could be constraining health- and movement-based outcomes in youth with VIs.

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CHAPTER 1

INTRODUCTION

This dissertation will consist of three studies that examine balance in youth with visual impairments (VIs). The first study will examine the construct and convergent validity of the Brief-Balance Evaluation Systems Test (Brief-BESTest) in youth with VIs. The second study will compare Brief-BESTest scores between youth with and without VIs. The third study will assess correlations between the Brief-BESTest and the Test of Gross Motor Develepmet-3 (TGMD-3) locomotor subscale scores in youth with VIs. This chapter will provide the overarching principles and foundations for this dissertation.

Background

Youth with VIs are prone to socio-determined health disparities (Krahn, Walker, & Correa-De-Araujo, 2015; United States Department of Health and Human Services, 2018b; 2005), are 50% more likely to become obese (Weil et al., 2002), and trend with decreased levels of health-related fitness, physical activity, and motor skill competence compared to peers without VIs (Augestad & Jiang, 2015; Houwen, Hartman, & Visscher, 2009a). Human balance (e.g., postural control, stability, gross body equilibrium, body management), which can be described as the ability to withstand falling (Winter, 1995), is an integral part of nearly every movement-based task a person may perform (Burton & Davis, 1992) and is a fundamental motor skill category (Gallahue, Ozmun, & Goodway, 2012). Therefore, it can be postulated that balance impairments will impede a child’s developmental, educational (e.g., physical education psychomotor outcomes), and/or health-related trajectories. If balance deficits exist in youth with VIs, those deficits and the resultant implications (e.g., associations, mediation, moderation of pertinent variables) should be universally assessed and addressed.

The ability to balance is influenced by several inertial/biomechanical characteristics (e.g., gravity, base of support, center of mass) and three physiological systems (i.e., visual, vestibular, proprioceptive). Because youth with VIs have impaired ocular systems, it could be hypothesized that applicable visual deficiencies would act as detriments to balance performance. However, it has been hypothesized that humans may be able to overcome a lack of visual information through sensory 'reweighting' to maintain postural control (Peterka, 2002).

Compared to youth without VIs, youth with VIs have presented with balance deficits (Bouchard & Tetreault, 2000; Rutkowska et al., 2015). However, comparisons to peers without VIs have been inconsistent or have lacked empirical rigor (Houwen, Visscher, Lemmink, & Hartman, 2009b). Balance assessments historically have been unidimensional or oversimplified; however, modern interpretations establish balance as being much more contingent and complex in nature (Horak, 2006). That is, balance is a plural construct made up of multiple systems influenced by dynamic sensorimotor interactions and contextual factors (Horak, 2006). To this end, traditional balance assessments have evaluated limited and/or redundant forms of balance (disregarding the interconnectedness of the balance systems) creating incomplete balance profiles and leading to improper conclusions of an individual's present level of performance. With modern conceptualizations of balance, practitioners can individually investigate, identify, and/or remediated underlying postural systems and mechanisms (Horak, Wrisley, & Frank, 2009).

Compared to traditional balance assessments, the Brief-BESTest (Padgett, Jacobs, & Kasser, 2012) may be a viable alternative. The Brief-BESTest is practitioner friendly, inexpensive, quick, assesses multiple balance systems, and has been shown to be valid and reliable. However, the Brief-BESTest has traditionally been utilized in adult/neurological populations (Jácome, Cruz, Oliveira, & Marques, 2016; O'Hoski et al., 2014; Padgett et al., 2012). The Brief-BESTest is an abridged version of the BESTest (Horak et al. 2009) which often shows reproducible properties in youth (Dewar, Clausa, Tucker, Ware, & Johnston, 2017), although, these results used the BESTest and not the Brief-BESTest, which employs specific items and scoring methods. Importantly, the Brief-BESTest should not to be confused with the Mini-BESTest (Franchignoni, Horak, Godi, Nardone, & Giordano, 2010). The Mini-BESTest is a different short form of the BESTest, however, it is more extensive than the Brief-BESTest. Although the Mini-BESTest is shorter than the BESTest, the Mini-BESTest has been described as lengthy and/or redundant which led to the creation of the Brief-BESTest (Padgett et al., 2012).

Validation studies of assessment scores (Messick, 1995; Pedhazur & Schmelkin, 1991) are continuously needed as validity is a perpetual process. All validation studies are comprised of scores which are historical in nature (i.e., temporal cross-sections). Further, test scores from specific populations (i.e., youth with VIs) or contexts need to be extensively vetted prior to the adoption of a test (American Educational Research Association, American Psychological Association, & the National Council on Measurement in Education, 2014; Cronbach & Meehl, 1955). Therefore, validation studies are needed before the Brief-BESTest can be viewed as accurate in youth with VIs. If found to have construct and convergent validity, the Brief-BESTest could: (a) be used to assess balance, (b) provide detailed balance profiles, (c) be correlated to relatable variables of interest (e.g., psychomotor objectives, physical activity measures, health indicators), and (d) lead to targeted balance interventions in youth with VIs.

No current normative values for the Brief-BESTest exist for younger populations. Therefore, to adequately interpret Brief-BESTest scores from youth with VIs, a group of youth without VIs will need to be collected for comparison. Further, after construct and convergent validity for the Brief-BESTest scores in youth with VIs are established and balance performance between youth with and without VIs is evaluated, Brief-BESTest scores in youth with VIs can be correlated with the locomotor subscale scores (i.e., run, gallop, hop, skip, horizontal jump, slide) of the TGMD-3 (Webster & Ulrich, 2017). Examining associations between Brief-BESTest scores and the locomotor subscale of the TGMD-3 in youth with VIs is vital as youth with VIs typically present with locomotive deficits (Wagner, Haibach, Lieberman, 2013). Importantly, balance has been described as a prerequisite for locomotion (Adolph, 2008; Nardini & Cowie, 2012), therefore, balance could be acting as a functional locomotor constraint in youth with VIs. Further, although stability skills have been recognized as a standalone fundamental motor skill category (Gallahue et al. 2012), the TGMD-3 does not explicitly assess balance skills as they are assumed within the TGMD-3.

While the overt contribution of balance skills to locomotor and/or object control (e.g., kicking, throwing, catching) skills has been highly debated, it has been suggested that methodological issues and underdeveloped conceptualizations of balance are to blame for historically inconsistent correlational findings between balance and locomotor/object control scores (Overlock & Yun, 2004). Further—traditionally—balance assessment scores have not associated or loaded well with other balance assessment scores (Burton & Davis, 1992; Overlock & Jun, 2004; Skaggs & Hopper, 1996) highlighting the inconsistencies that have plagued balance as a construct. While the psychometric properties of balance assessments have customarily been a conundrum, modern balance-based skills have been shown to perform well alongside locomotor, object control, and other balance skills in contemporary motor competence models (Luz, Rodrigues, Almeida, & Cordovil, 2016; Rudd et al., 2015). Therefore, it is likely that the Brief-BESTest can further elucidate the role of balance as a fundamental motor skill.

Theoretical and Paradigmatic Underpinnings

A post-positivism paradigm will be adopted for this dissertation. The paradigmatic allegiance will (a) guide the research process, (b) make assumptions explicit, (c) give context to answers, and (d) guide future directions (Macdonald et al., 2002). Therefore, post-positivistic assumptions will permeate every act of this dissertation (Macdonald et al., 2002). According to Guba (1990, p. 18), research paradigms are characterized by three foundational questions:

a) *Ontological*: What is the nature of the "knowable?" Or what is the nature of "reality?"
b) *Epistemological*: What is the nature of the relationship between the knower (the inquirer) and the known (or knowable)?
c) *Methodological*: How should the inquirer go about finding out knowledge?

Based on these questions, Guba (1990, p. 23) subsequently elucidates the assumptions of post-positivism:

a) Ontology: *Critical realist*—reality exists but can never be fully apprehended. It is driven by natural laws that can be only incompletely understood.
b) Epistemology: *Modified objectivist*—objectivity remains a regulatory ideal, but it can only be approximated, with special emphasis place on external guardians such as the critical tradition and the critical community.
c) Methodology: *Modified experimental/manipulative*—emphasize critical multiplism. Redress imbalances by doing inquiry in more natural settings, using more qualitative methods, depending more on grounded theory, and reintroducing discovery into the inquiry process.

In summary, the post-positivism paradigm asserts that there is an independent reality to be investigated but concedes that all observations are fallible (Onwuegbuzie, Johnson & Collins, 2009). Because all observations are imperfect and biased, post-positivism emphasizes the use of inferential statistics and probabilities (e.g., *p*-values, confidence intervals) to make correct (but not certain) generalizations (Onwuegbuzie et al., 2009).

Purpose, Research Questions, and Hypotheses

Study 1. The purpose of this study was to examine the construct and convergent validity of Brief-BESTest scores in youth with VIs. This study will use a descriptive-analytic design to examine the construct and convergent validity of the Brief-BESTest in youth with VIs. It was hypothesized that Brief-BESTest scores will load as a singular latent variable (i.e., global balance) and that Brief-BESTest total scores will significantly associate with the total scores of additional balance assessments.

Study 2. The purpose of this study was to compare Brief-BESTest scores between youth with and without VIs. This study will use a descriptive-analytic design to compare item scores and total scores on the Brief-BESTest. It is hypothesized that youth with VIs will score significantly lower than youth without VIs on the individual item scores and total scores of the Brief-BESTest.

Study 3. The purpose of this study was to investigate associations between Brief-BESTest scores and the TGMD-3 locomotor subscale scores in youth with VIs. This study will use a descriptive-analytic design to investigate relationships between the Brief-BESTest and the TGMD-3 locomotor subscale. It is hypothesized that all item and total score bivariate correlations between the Brief-BESTest and the TGMD-3 locomotor subscale will be significant in youth with VIs.

Delimitations and Limitations

Delimitations. This section will define the scope/boundaries of this dissertation. For this dissertation, balance abilities in youth with VIs, and to a secondary degree, youth without VIs (i.e., Study 2), will be investigated. The main rationale behind this selection was that balance research in youth with VIs is underdeveloped (e.g., lacks rigor, conflicting findings). This dissertation will focus on youth with VIs in New York, Florida, and North Carolina and youth without VIs in South Carolina. The selection of these locations is due to access and feasibility.

The sample will be comprised of youth with VIs aged 8-20 years, of multiple VIs, races, comorbidities, and biological sexes. Any student with a VI who provides consent will be included (i.e., no exclusion criteria). The wide age range and inclusive criteria are necessary because youth with VI are a low prevalence population. However, in Study 2, youth without VIs will be excluded if they (a) have a VI and/or (b) have a documented disability. Analyses within these studies will be variable-centered as opposed to person-centered (Muthén & Muthén, 2006). However, descriptive statistics and or additional analyses (if found to be appropriately powered *post hoc*) will be used in an attempt to control for clusters/stratifications through dummy coding and multivariate regression and/or covariate analyses when appropriate and allowable.

Finally, four physical balance assessments and one psychological balance assessment will be utilized. Of the four physical assessments, the Brief-BESTest has been selected for its practicality and its ability to assess multiple balance systems. Postural sway and the 360-degree turn test have been selected as they are well established, laboratory-based balance assessments. The Lower Quarter Y-Balance Test (LQYBT) has been included for its growing popularity, simplicity, and application to athletic-based settings. The Activities-specific Balance Confidence Scale (ABC Scale) was selected to provide a psychological measurement. Further, the ABC Scale is regularly included in balance validation studies.

For Study 3, only the TGMD-3 locomotion subscale will be used due to time constraints. Further, from a developmental standpoint, balance precedes locomotion meaning it would be logical to examine the role of balance in locomotion before examining the role of balance in object control skills.

Limitations. Although carefully prepared, this dissertation will have notable limitations. All participants recruited for this study will be recruited through convenience sampling (i.e., selection bias, non-probability sampling), therefore, the results of this study will lack generalizability. However, due to the low prevalence and accessibility of youth with VIs, convenience sampling is the only realistic option. Further, while it is hoped that the total sample size for this study will reach ≥ 100 participants, this sample size will be reached by combining participants of various ages (i.e., 8-18 years), biological sexes, vision levels, and comorbidities (i.e., Study 1).

It is important to note that obtaining a sample size of ≥100 participants would be viewed as substantial within the VI literature. Yet, this heterogeneous sample will also decrease the generalizability and specificity of the results. To address this issue, attempts will be made to control for and/or present data by age-band, biological sex, and vision level, and comorbidity. Unfortunately, it is unlikely that the necessary assumptions and statistical power will be reached to complete advanced stratified/cluster or invariance analyses. As a result, cross-tabulations, dummy coding, and/or multivariate regression will be used to assess the influence of these potentially confounding variables.

Of the descriptive variables, vision level is the most negatively skewed meaning those with the lowest level of vision are most likely to be underrepresented in this sample. All attempts will be made to maximize the enrollment of youth with VIs of all vision levels. Additional limitations include lack of effort and social desirability response bias; however, proactive efforts will be made to build rapport and motivate participants to try their best and to give honest answers when answering questions.

Significance and Innovation

Significance. This dissertation is significant as it has the potential to validate a system-specific, practitioner-friendly, quick, and inexpensive balance assessment in youth with VIs. By validating the Brief-BESTest, practitioners and researchers will be able to pinpoint what specific balance systems and/or mechanisms should be targeted to improve balance performance in youth with VIs. Further, positive outcomes from this dissertation would facilitate future research exploring associations between the Brief-BESTest and related variables of interest (e.g., psychomotor objectives, physical activity measures, health indicators).

Innovation. This dissertation is innovative because it will be the first to explore system-specific balance performance (i.e., Brief-BESTest) in youth with VIs, compare those results to youth without VIs, and explore associations between the Brief-BESTest and the TGMD-3 in youth with VIs.

CHAPTER 2

LITERATURE REVIEW

The purpose of this chapter is to provide a comprehensive literature review informing all three studies. The chapter is organized into the following sections: (a) the population of interest (b) a background of balance and (c) research regarding balance in youth with VIs.

Population of Interest

Prevalence and epidemiology of VI. According to the U.S. Census Bureau (2016), over 539,000 or 0.7% of people under the age of 18 years have a self-reported ‘vision difficulty.’ Per a single “Yes/No” census question, vision difficulty is defined as someone who claims to be “blind or have serious difficulty seeing even when wearing glasses” (U.S. Census Bureau, 2016). However, it has been purported that the self-reporting of VI through the census process lacks sensitivity (Hiller & Krueger, 1983). Unfortunately, the prevalence rates of VI in Western countries has been shown to range widely between 3 per 10,000 to 61 per 10,000 cases (Kong, Fry, Al-Samarraie, Gilbert, & Steinkuller, 2012; Steinkuller et al., 1999; Mervis, Boyle, & Yeargin-Allsopp, 2002; National Academies of Sciences, Engineering, and Medicine, 2016) depending on the definition, age, and/or origin of the prevalence data (Houwen, Visscher, Lemmink, & Hartman, 2008; Mervis et al., 2002). Factors including race/ethnicity, biological sex, family history of eye disease, socioeconomic status, and geographic location influence the prevalence of VI (National Academies of Sciences, Engineering, and Medicine, 2016).

Across all grades and states it is believed that the United States has over 50 million youth, over 6.5 million of which (aged 3-21 years) receive services under Part B - Assistance for Education of All Children with Disabilities of the Individuals with Disabilities Education Act (IDEA) (United States Department of Education, 2017a; 2017b). Of the youth who received services under Part B of the IDEA, over 27,000 of those were classified under the VI category (United States Department of Education, 2017b). Therefore, the percentage distribution of youth with disabilities served who have VIs equates to 0.4% (i.e., out of 6.5+ million) while the total percentage of prevalence of youth with VIs across all grades and states equates to 0.0005% (i.e., out of 50+ million youth). However, the VI count only includes youth who are receiving services and does not include youth counted in a separate disability category. It has been suggested that the actual number of youth with VIs may be upwards of 3-4 times higher than the 27,000+ youth currently served by Part B of the IDEA (Kirchner & Diament, 1999). Regardless, youth with VIs have been classified as a low prevalence population (United States Department of Education, 2003) and likely make up less than 1% of the student population in the United States. Irrespective of the prevalence rate, youth with VI are an at-risk population which deserve empirical investigation and support.

Childhood blindness in the United States accounts for only 4% of total blindness but as Gilbert and Foster (2001) elucidated, youth with blindness experience 40 more years of VI compared to those who experience adult-onset vision. Unfortunately, a national registry for the blind and visually impaired does not exist in the United States and it has been purported that a majority of schools for the blind do not typically maintain and/or share data regarding the cause of blindness in their youth (Kong et al., 2012). Based on a survey sent to schools for the blind in the United States, out of 56 schools, 16 schools (28.6%) from 15 states supplied data on over 3,000 youth. Based on the survey, the leading causes of blindness were cortical VI (18%), optic nerve hypoplasia (15%), and retinopathy of prematurity (14%) while the primary anatomic sites causing VI were the retina (30%) and the optic nerve (23%) (Kong et al., 2012). In the United States, most childhood blindness was found to be hereditary (e.g., albinism, congenital cataracts with family history, retinitis pigmentosa) or due to perinatal factors (i.e., from 22 completed weeks [154 days] of gestation to seven completed days after birth). However, these data were not comprehensive as (a) less than 10% of youth with VI attend schools for the blind (American Printing House for the Blind, 2017), (b) admission criteria at schools for the blind may vary, and (c) schools for the blind do not necessarily use or employ equivalent VI definitions (Kong et al., 2012).

The visual system. The ocular system is complex. Good vision requires appropriate functioning of the optical and perceptual systems (Schwartz, 2010). A properly functioning visual system is one that “effectively capture(s) light from an object and translate it into neural impulses that are processed in the brain. The visual system consists of the eye, the pathways that conduct neural impulses from the eye to the brain, and specific areas within the brain to interpret the signals” (National Academies of Sciences, Engineering, and Medicine, 2016, p. 57). There are several functions that the visual system performs (see Table 2.1). Figure 2.1 is an anatomical diagram of the human eye. The National Academies of Sciences, Engineering, and Medicine (2016, p. 57-58) thoroughly describes how the visual system operates:

> Light enters the eye through the cornea, which helps refract light. The pupil is the small opening at the center of the iris, which functions like the shutter of a camera to regulate the amount of light entering the pupil and expanding and contracting the opening in response to ambient light. The lens further focuses light on the retina, with muscles controlling the lens shape to differentially focus on objects based on distance from the eye. Between the lens and the retina is the vitreous humor—a clear gel that gives the eye its spherical shape and keeps the retina in place. The retina includes blood vessels and a thin layer of light-sensitive tissue (photoreceptors called cones and rods), which translate light energy into neural impulses. Within the retina, the macula has millions of tightly packed cones that are concentrated at the fovea and are responsible for sharp, detailed central vision and color vision. Surrounding the macula, rods are more sensitive to light and are responsible for night vision, peripheral vision, and the ability to detect motion. Photoreceptors convert light into electrical signals, which are relayed to the brain through the optic nerve. Within the brain, visual information is parsed and relayed along various pathways, and eventually interpreted as a recognizable image.

VIs occur because of damage or dysfunction to a structure(s) within the visuo-perceptual system (see Table 2.2). However, two people with the same diagnosis could greatly differ in terms of their visual abilities and/or symptomologies. Further, because an infinite number of conditions and severities are possible, vision impairment is highly variable from individual to individual. For common conditions which cause VIs, see

Table 2.3. Factors such as maturation, age, personal lifestyle, and changes in body chemistry can influence a VI (Schwartz, 2010) as well as medications (Levack, 1994). For additional information related to the visual effects of selected syndromes and diseases on individuals with VIs, see Schwartz (2010, 188-191). For supplementary information on (a) the sequence of visual development or (b) adaptations for corresponding eye conditions, see Levack (1994, p. 104-155).

Visual classifications. The International Blind Sports Federation (2019; B1-B3) and the United States Association of Blind Athletes (2019; B4) use a common classification system for those with VIs. The sport-based classifications are as follows:

a) B1: No light perception in either eye up to light perception, and an inability to recognize the shape of a hand at any distance or in any direction.
b) B2: From ability to recognize the shape of a hand up to visual acuity of 20/600 and/or a visual field of less than 5 degrees in the best eye with the best practical eye correction.
c) B3: From visual acuity above 20/600 and up to visual acuity of 20/200 and/or a visual field of less than 20 degrees and more than 5 degrees in the best eye with the best practical eye correction.
d) B4 (United States Association of Blind Athletes *Recognized Low Vision Classification*): From visual acuity above 20/200 and up to visual acuity of 20/70 and a visual field larger than 20 degrees in the best eye with the best practical eye correction.

However, the World Health Organization (2016, ICD-10 H54) uses more specific classifications (see Table 2.4):

a) H54.0; Blindness, binocular (VI categories 3,4,5 in both eyes)

b) H54.1; Severe VI, binocular (VI category 2)

c) H54.2; Moderate VI, binocular (VI category 1)

d) H54.3; Mild or no VI, binocular (VI category 0)

e) H54.4; Blindness, monocular (VI categories 3, 4, 5 in one eye and categories 0, 1, 2 or 9 in the other eye)

f) H54.5; Severe VI, monocular (VI category 2 in one eye and categories 0, 1 or 9 in other eye)

g) H54.6; Moderate VI, monocular (VI category 1 in one eye and categories 0 or 9 in other eye)

h) H54.9; Unspecified VI (binocular) (VI category 9)

Motor development, physical activity, and health-related discrepancies. Youth with disabilities are prone to socially-determined health gaps. *Healthy People 2020* "recognizes that what defines individuals with disabilities, their abilities, and their health outcomes more often depends on their community, including social and environmental circumstances" (United States Department of Health and Human Services, 2018b). As such, five key socio-determined factors have been identified which could influence and/or determine the health of youth with VIs: (a) economic stability, (b) education, (c) social and community context, (d) health and health care, and (e) neighborhood and built environment. While the World Health Organization has published 'principles of action' toward achieving health equity among those with disabilities, large gaps still exist.

In general, youth with VIs have been found to be sedentary (Longmuir & Or, 2000) and overweight (Lieberman, Byrne, Mattern, Watt, & Fernandez-Vivo, 2010; Lieberman & McHugh, 2001). These concerns are heightened by the likelihood that youth with VIs are 50% more likely to become obese in adulthood when compared to those without VIs (Weil et al., 2002). Further, youth with VIs have been shown to trend with decreased levels of health-related fitness, physical activity, and perceived and actual motor competence when compared to peers without VIs (Augestad & Jiang, 2015; Brian, Haegele, & Bostick, 2016; Houwen et al., 2009a; Kozub & Oh, 2004; Lieberman et al., 2010; Lieberman & McHugh, 2001; Longmuir & Or, 2000; Stuart, Lieberman, & Hand, 2006; Wagner et al., 2013). Youth with VIs may also be susceptible to mental health issues (Augestad, 2017).

Summary. Youth with VIs are a low prevalence population. Anatomical/physiological descriptions of the visual system were presented. There are several classification systems, etiologies, and factors regarding VIs; however, each person experiences a specific VI differently. Youth with VIs trend with lower levels of motor skill competence, health-related factors, and physical activity. Further, youth with VIs are more likely to be sedentary and are at an increased risk for becoming obese in adulthood.

Background of Balance

The nature of balance. The nature of balance is a highly complex, contingent, and multifaceted (Horak, 2006). According to Reed (1989), balance is an act, not a state. Multiple definitions and conceptualizations of balance/stability/posture have been described, however, within this document human balance will be defined as “a multidimensional concept, referring to the ability of a person not to fall" (Pollock, Durward, Rowe, & Paul, 2000, p. 405). In physical education and/or related movement-based settings, balance (whether subvert or overt) is needed for nearly every physical activity. In an overt sense, balance is needed for certain activities such as gymnastics, dancing, golf, slacklining, climbing, or shooting. However, balance is necessary for all forms of static and dynamic postures and movements (e.g., hopping, shooting a soccer ball, throwing a baseball). Further, many lifespan activities such as wheel-, ice-, snow-, and water-based actions rely heavily on adequate balance (e.g., bicycling, skateboarding, rollerblading, ice skating, surfing, standup paddle boarding, water skiing, wakeboarding, snow skiing, snowboarding, etc.). Balance also is applied to a variety of everyday tasks (e.g., walking on a slippery surface, using a ladder, traversing terrain, reaching for something overhead or when standing on a stool).

Two forms of balance have been described in the literature (Bass, 1939): static balance (i.e., equilibrium in one position) and dynamic balance (i.e., equilibrium through a series of changing positions). Additionally, balance has been described as a task-specific entity. Burton and Davis (1992, p. 17) elaborate: "…although [some] studies suggest that balance is a fairly unified general ability underlying the performance of a variety of movement skills…there also is a considerable amount of research indicating that balance is specific to the task being performed." In line with Burton and Davis (1992), Reed (1989) has stated that isolated environmental contexts and singular mechanisms regarding posture and movement are 'biological fictions.' These realities have led to considerable debates and issues within balance research.

Determinants and theoretical considerations for balance. It is known that three physiological systems (i.e., visual, proprioceptive, vestibular; Huxham, Goldie, & Patla, 2001; Peterka, 2002), biomechanical aspects, inertial properties, environmental contexts, task characteristics, as well as motor learning principles are determinants of functional balance control (Huxham et al. 2001). Specifically, "balance or equilibrium is obtained through the combined efforts of simple reflexes, proprioceptive information relayed to the cerebrum and cerebellum, and activation of the reticular formation, the vestibular apparatus, voluntary movements, and visual information" (Singer, 1975, p. 59). Due to the complexity of balance, Huxham and colleagues (2001) have provided a guiding model for conceptualizing balance and its contributing factors (see Figure 2.2). Further, Pollock et al. (2000) provide a practical model which highlights two forms of strategies that can be used to keep balance (i.e., fixed-support: ankle or hip strategy; change-in-support: stepping, grasping) as these strategies can be useful for qualitative balance analyses (see Figure 2.3).

Based on the model produced by Huxham et al. (2001), balance performance depends on (a) the environment and (b) the task. Huxham and colleagues further extend their model by integrating Gentile's taxonomy of tasks (1987) to explicate that the task and the environment subsequently influence (a) the amount of information that must be processed while keeping balance and (b) the biomechanical features of a given task. Regarding information processing (i.e., cognitive demands), task and environmental characteristics influence how an individual plans a strategy or uses timing while keeping their balance and/or to achieve a goal. Further, how one experiences things (e.g., open/dynamic vs. closed/controlled tasks) or learns to balance (e.g., lived experiences, random vs. blocked practice) can be very important. Balance is situated as being comprised of (a) postural control (i.e., biological work to remain upright and counterbalancing) and (b) equilibrium control (i.e., intersegmental stabilization despite acted forces). Last, postural and equilibrium control are stated to be influenced by three mechanistic categories: proactive, predictive, and reactive mechanisms.

Proactive balance mechanisms, which are heavily grounded by the visual system, enable a person to perceive their environment so that they may act judiciously. Predictive balance mechanisms are somewhat similar in nature (if not subservient to) proactive balance measures, as these mechanisms attempt to sustain intersegmental stability based on "learned awareness" and movement/muscle relationships (Huxham et al., 2001, p. 93). The final mechanism category concerns reactive balance mechanisms. These balance mechanisms are postural reflexes. Huxham et al. (2001, p. 93) summates the roles of these mechanisms by stating that: "the normal balance system is believed to meet…varied demands by a mixture of proactive visual and predictive mechanisms, with reactive processes playing an important role when proactive ones fail, or perturbation is unexpected."

Issues of measurement variability and validity. Importantly, questions of balance assessment variability and/or validity have been raised. According to Reed (1989, p. 5), "the phenomena of posture have not fit in well with most accounts of movement." Methodological issues, underdeveloped conceptualizations of balance, and low/insignificant loadings (Burton & Davis, 1992; Overlock & Jun, 2004; Skaggs & Hopper, 1996) between fundamental motor skills and/or other balance assessments (Drowatzky & Zuccato, 1967; Hempel & Fleishman, 1955; Tsigilis, Zachopoulou, &

Mavridis, 2001) have led some researchers to questions the role of balance in movement (Klavina, Ostrovska, & Campa, 2017; Singh et al., 2015; Ulrich & Ulrich, 1985; Winstein, Gardner, McNeal, Barto, & Nicholson, 1989). However, such a conclusion has been regularly contended (Chew-Bullock et al., 2012; Logan, Robinson, & Getchell, 2011; Loovis & Butterfield, 2000; Mache & Todd, 2016; Wang, Long, & Liu, 2012) supporting the stance put forth by Reed (1989, p. 21) who posited that "a key factor in constraining motor variability into functional action is [the] adaptable and flexible nesting of movement and posture."

Assessments may use static and/or dynamic balance, may be more practical or more laboratory-based, or may conceptualize balance in a very specific (e.g., walking a balance beam) or general way. While some assessments may have a variety of activities (e.g., perturbed and non-perturbed), most assessments (if not all) lack environmental, biomechanical, and/or cognitive considerations, or do not adequately reproduce proactive, predictive, and/or reactive balance mechanisms in authentic and dynamic settings (Huxham et al., 2001). "It appears likely that our current inability to evaluate this highest level of balance objectively contributes to the poor predictive value of available tests" (Huxham et al., 2001, p. 96). Therefore, more empirically-authentic balance assessments are needed. As Reed, (1989, p. 6) notes, "a primary function of posture is the integration of movements into coordinated action sequences. Such phenomena simply do not emerge in experimental paradigms devoted to isolated movements under constrained conditions."

Balance as a lifespan and fundamental motor skill. Assaiante and Amblard (1995) have proposed an ontogenetic model in reference to human balance control

(Assaiante, 1998) across the life course. This model is grounded by two principles: the support surface and the continuous effective organization and reorganization of one's degrees of freedom. Using this framework Assaiante and Amblard (1995) propose four successive periods for the ontogenesis for balance control. The first period is defined as birth until upright stance (~1 year of life) which is marked by "a clear cephalocaudal gradient in the development of…postural responses" (Assaiante & Amblard, 1995, p. 19) which begins at the neck, transitions to the trunk, and finishes at the legs. Henceforth, Assaiante and Amblard (1995) suggest that—with the development of bipedal posture—equilibrium control becomes more global in nature (as opposed to segmental). This second phase is categorized by "a gradual mastery of the equilibrium constraints" (Assaiante & Amblard, 1995, p. 20) (i.e., coordination development of the ankle, knee, hip, and head) which lasts from upright stance (~1 year of life) until around the age of 6. After the second phase, youth aged 7-10 years begin to perform with adult like postural responses (Nougier, Bard, Fleury, & Teasdale, 1998; Shumway-Cook & Woollacott, 1985; Woollacott, Shumway-Cook, & Williams, 1989).

> The third and fourth periods concern "head stabilization in space [and] a basic means of descending temporal organization of balance control" (Assaiante & Amblard, 1995, p. 23). The third period, from about age 7 to sometime in adolescence, is characterized by the refinement of head stabilization in balance control. The fourth and last period, which begins in adolescence and extends through adulthood, is characterized by refined control of the degrees of freedom of movement in the neck. (Haywood & Getchell, 2014, p. 247)

Given the utility of the ontogenetic model of postural and locomotor balance control in humans as posited by Assaiante (1998) and Assaiante and Amblard (1995), the development of balance should be appreciated across the lifespan as a critical component of movement development and sustainability in function and not only investigated during infancy and/or older adulthood. Importantly, balance is a variable that is developmentally appropriate at all ages, and therefore, can be used to assess motor skills across the lifespan (Leversen, Haga, & Sigmundsson, 2012; Sigmundsson, Lorås, & Haga, 2016).

Is balance a (fundamental) motor skill or ability? Motor abilities can be defined as general traits or capacities of an individual that underlie the performance of a variety of movement skills (Magill, 1985). Motor abilities are presumed to be relatively stable (Schmidt, 1982; Keogh & Sugden, 1985), however, it has been suggested that motor abilities can change (Fleishman & Hempel, 1955). Several researchers have stated that balance should be classified as a motor ability (i.e., stable/general ability) and not as a motor skill (Burton & Rodgerson, 2001; Fleishman, 1962; Holfelder & Schott, 2014). Contradictingly, balance has been categorized as a motor skill, ability, and/or state within the literature (Burton & Davis, 1992). However, it has been suggested that balance performance cannot be concretely generalized across a multitude of tasks and environments (Burton & Davis, 1992). Further, because balance abilities can typically be improved with practice, it is assumed within this document that—as acknowledged by Gallahue and colleagues (2012)—balance is a motor skill (albeit elusive) and not a motor ability.

Although balance has been categorized as a fundamental motor skill (Gallahue et al. 2012), the role of balance as a fundamental motor skill has been downplayed and/or under investigated in the field of motor development (Rudd et al., 2015). For example, there is no balance subscale in the TGMD-2 or -3 (Ulrich, 2000; Webster & Ulrich, 2017) which is one of the most popular fundamental motor skill assessments used in the United States. While Ulrich and Ulrich (1985) found that correlations between the balance subscale of the Bruininks-Oseretsky Test of Motor Proficiency (BOT, Bruininks, 1978) and qualitative stages of development for six fundamental motor skills (Seefeldt & Haubenstricker, 1974-1976) in youth aged 3-5 years were inconclusive, modern balance-based skills have been shown to perform well alongside locomotor, object control, and other balance-like skills in contemporary motor competence models (Luz et al., 2016; Rudd et al., 2015). Further, in Europe, balance-related skills have been consistently valued and utilized to measure motor competence in youth (i.e., KörperkoordiantionsTest für Kinder; Kiphard & Shilling, 1974). Therefore, it is likely that balance is, and plays a role, as a fundamental motor skill.

Summary. Balance is influenced by reflexes, afferent/sensory sources (i.e., visual, proprioceptive, vestibular) and efferent/voluntary movements (Singer, 1975). Balance performance is further influenced by environmental and inertial characteristics. As such, balance is a complex, task-specific skill that is foundational to the development and sustainability of effective movement function across the life-course and should be classified as a (fundamental) motor skill and not as a ‘general’ trait or ability. Huxham et al. (2001) has provided a useful model for conceptualizing balance. The field of balance assessment has been plagued by validity and measurement variability issues.

Balance of Youth with VIs

Regarding sensory contributions to balance control, vision has been shown to play a predominate role in the acquisition of posturo-kinetic skills from infancy up to the age of six (Assaiante & Amblard, 1995). Due to impairments to the visual modality, it is not surprising that infants and children with VIs have been shown to present with impaired motor delays when compared to peers without VIs (Adelson & Fraiberg, 1974; Griffin, 1981; Murphy & O'Driscoll, 1989). According to Rosen (1997, p. 173) "vision stimulates, guides, and verifies [an individual's] interaction with the environment. It stimulates motor activities and the development of cognitive relationships." (p. 173).

> To date, the favored explanations of the adverse impact of VI on motor development have been that: (i) visual feedback is necessary for the refinement of movements, therefore a VI will result in less opportunity for this to occur; (ii) the infant or child with a VI is less motivated to move about their environment as they cannot, for example, see toys across the room, and are less able to avoid hazards during exploration (Warren, 1994); and (iii) children with a visual disability are often overprotected and provided with fewer opportunities than sighted children for exploration and independence (Dobree & Boulter, 1982). (Wyver & Livesey, 2003, p. 26)

However, from the age of six years and on, visual dominance appears to gradually decrease (Assaiante & Amblard, 1995) and individuals with VIs may be able to make-up lost ground regarding basic motor milestone as they age, albeit to varying degrees and contexts, possibly due to sensory reweighting (Peterka, 2002) and/or lifestyle/environmental circumstances (Schneekloth, 1989). Nakata and Yabe (2001) have posited that blindness at birth may not affect the automatic postural response system, “but may affect a volitional act mediated through the motor cortex” (p. 36).

Regarding balance performance, comparisons to those without VIs have been equivocal and/or controversial (e.g., variability of assessments, assessment validity concerns; low: empirical rigor, application to the real world, utility for practitioners, loadings/relationships). When scored out of 16 points, 13 studies that emphasized or included a balance assessment in youth with VIs averaged a score of 7 (Houwen et al., 2009b; see Table 2.5). Houwen et al. (2009b) went on to state that there is insufficient evidence that degree of vision is associated with dynamic and static balance in youth with VIs. In fact, in some studies, balance performance qualities have been shown to not be different from individuals without IVs (Johnson-Kraemer, Sherwood, French, & Canabal, 1992; Nakata & Yabe, 2001).

Sampling and sample sizes. To the author’s knowledge, no studies have used random sampling of youth with VIs which leads to concerns about the generalizability of results. Also, it can be extremely difficult to obtain significant sample sizes across multiple age and vision levels, primarily from individuals of the B1 and B2 vision classification. Therefore, underrepresentation of youth in lower vision categories is common. Most studies either examine very specific ranges or combine youth into larger or cumulative groupings for analysis.

Regarding sample size, most balance-related studies utilizing youth with VIs have sample sizes ≤ 30 (Aki et al., 2007; Bouchard & Tetreault, 2000; Brambring, 2006a; Caputo et al., 2007; Engel-Yeger, 2008; Gipsman,1981; Haibach et al., 201l; Häkkinen, Holopainen, Kautiainen, Sillanpää, & Häkkinen, 2006; Johnson-Kraemer et al., 1992;

Navarro, Fukujima, Fontes, Matas, & Prado, 2004; Ribadi, Rider, & Toole, 1987; Schneekloth, 1989; Wyver & Livesey, 2003). Three studies have managed to recruit between 48 and 67 participants with VIs (Case, Dawson, Schartner, & Donaway, 1973; Houwen et al., 2008; Pereira, 1990) while three studies have reached over 100 participants (Buell, 1950; Leonard, 1969; Rutkowska et al., 2015). Of the three studies that have reached over 100 participants with VIs, Buell (1950) was able to enroll an astounding 865 participants. Overall, it should be concluded that a bulk of the literature surrounding balance performance in youth with VIs has been plagued by suboptimal levels of statistical power (i.e., low sample sizes).

Common assessments. Several assessments have been used to assess and/or compare the balance performance of youth with VIs. Assessments which have been utilized include versions and/or combinations of the BOT (Aki, Atasavun, Turan, & Kayihan, 2007; Bouchard & Tetreault, 2000; Rutkowska et al., 2015; Schneekloth, 1989), the Movement Assessment Battery for Children (MABC, Caputo et al., 2007; Engel-Yeger, 2008; Houwen et al., 2008; Wyver & Livesey, 2003), other clinical motor assessments (Brambring, 2006a; Navarro et al., 2004), stabiliometry (Gipsman,1981; Haibach, Lieberman, & Pritchett, 2011; Johnson-Kraemer et al.,1992; Ribadi et al., 1987), motor educability tests (Buell, 1950; Case et al., 1973), or more practical balance assessments (Häkkinen, Holopainen, Kautiainen, Sillanpää, & Häkkinen, 2006; Leonard, 1969; Pereira, 1990; Ribadi et al., 1987). Due to the wide variance of assessments, comparisons between studies can be difficult as different assessments may produce different results. Further, it is important to note that certain researchers have examined static, dynamic, or static and dynamic forms of balance. Therefore, findings are highly influenced by focus and context.

***Results based on the BOT balance subscale*.** The BOT is one of the most widely utilized motor assessments for youth and was first published by Bruininks (1978) and later updated (including the introduction of a short form) in 2005 by Bruininks and Bruininks. The current version of the full BOT balance subscale consists of nine items: (a) standing with feet apart on a line for up to 10 seconds with eyes open (b) and closed, (c) walking forward on a line for up to six steps with eyes open, (d) standing on one leg on a line for up to 10 seconds with eyes open (e) and closed, (f) walking forward heel to toe on a line for up to six steps with eyes open, (g) standing on one leg on a balance beam for up to 10 seconds with eyes open (h) and closed, and standing heel-to-toe on a balance beam for up to 10 seconds with eyes open. Each of the nine assessments is scored from 0-4 for a total of 36 points for the full BOT balance subscale. All versions of the BOT have been said to be valid and reliable (Bruininks, 1978; Bruininks & Bruininks, 2005), however, significant concerns regarding the BOT have been raised (Deitz, Kartin, & Kopp, 2007; Hattie & Edwards, 1987). These concerns have not stopped the BOT from being utilized in youth with VIs.

(Note: for the following sections n_{VI} will correspond to youth with VIs while n_{WO} will denote youth without VIs. A single study will include n_{HI} which will denote a sample of youth with hearing impairments). Schneekloth (1989), Bouchard and Tetreault (2000), Aki et al. (2007), and Rutkowska et al., 2015 all had participants with VIs complete the balance subscale using a version of the BOT. Results from all four studies concluded that balance was impaired in youth with VIs. Bouchard and Tetreault (2000; $n_{\mathrm{VI}} = 30$, $n_{\mathrm{WO}} =$

30, N = 60; 8-13 years) concluded that youth with VIs had poorer balance. Further, improved performance on the balance subtest was linked to higher percentile ranks for fine and gross motor skills. However, for the low vision group, the same association was not present for the fine motor skills. Schneekloth (1989, n_{VI} = 24, n_{WO} = 12, N = 36; 7-13 years), who only utilized the non-sight dependent items form the BOT, found that there were significant differences in motor proficiency between those without VIs, however, the balance subscale results were not parsed out. Schneekloth (1989) went on to conclude that the discrepancies between the two populations were due to (a) motor passivity (i.e., unwillingness to explore), (b) self-manipulation versus environmental-manipulation, and (c) immature play behaviors.

Rutkowska et al. (2015, N_{VI} = 127, 6-16 years) in one of the most impressive sample sizes to date examined relationships between the balance subscale and personal traits (e.g., age, sex). While no comparison made to individuals without VIs, the authors were able to use normative values for the BOT to make comparisons. However, it is important to note that these youth were sampled in Poland; therefore, the BOT normative values may not be ideal for comparison. Overall, age and degree of vision were found to significantly influence balance performance, but not sex. Based on the normative comparisons, 21% and 58% of individuals with VIs were found to be below or well below peers without VIs respectively—highlighting noteworthy balance deficits within most of the sample (i.e., 79%). A final study by Aki et al. (2007, $n_{\mathrm{VI\text{-}1}}$ = 20, $n_{\mathrm{VI\text{-}2}}$ = 20, N_{VI} = 40; 8.9 and 8.10 years) examined the effects of an intervention using the BOT short form, however, the study did not have a control group. This review will not be focusing on interventions. However, for current purposes, pre-test scores can be used to add breadth to this review. Based on mean pre-test balance scores (out of 12 points), participant balance performances within two VI groups were not maximal (n_{VI-1} = 5.65; *SD* = 3.37, n_{VI-2} = 4.60; *SD* = 2.90).

Results based on the MABC balance subscale**.** The MABC utilizes specific static and dynamic balance tasks which can vary across age bands (i.e., 3-6 years, 7-10 years, 11-16 years). The first age band assesses one-leg balance (on both legs) up to 30 seconds, walking heels raised on a line up to 15 steps, and jumping forward on mats up to 5 jumps. The second age band assesses one-board balance (on both legs) up to 30 seconds, walking forward on a line heel-to-toe up to 15 steps, and one-leg forward hopping on mats (on both legs) up to 5 hops. The third age band assesses two-board in-line balance up to 30 seconds, walking backward on a line heel-to-toe up to 15 steps, and zig-zag forward hopping on mats (on both legs) up to 5 hops. The MABC has also been found to be reliable and valid and includes normative values (Henderson & Sugden, 1992; Henderson, Sugden, & Barnett, 2007). Much like the BOT, the MABC has been a popular motor assessment for youth with VIs. Each item is scored on a five-point scale were 0 equals no impairment and 5 equates to severe impairment (i.e., 0 = good).

According to Wyver and Livesey (2003), Caputo et al., (2007), Engel-Yeger (2008), Houwen et al. (2008), youth with VIs present with balance deficits. Although the sample size was low, Wyver and Livesey (2003, n_{VI} = 15, n_{WO} = 15, *N* = 30; 6-12 years), who manipulated occlusion and non-occlusion, descriptively concluded (i.e., only four with severe VIs, did not run inferential statistics) that those with severe (versus moderate) VIs had impaired balance performance. The authors went on to conclude that differing interventions may be needed for severe versus moderate VIs. Caputo et al. (2007 n_{VI} =

19, n_{WO} = 23, N = 42; 4-6 years) found that youth with VIs significantly improved their static and dynamic performance due to improvements of balancing on one leg and walking with heels raised (i.e., no difference for jumping) post-strabismus surgery. This result highlighted (that for certain conditions) surgery may be a viable solution for improve perceptual-motor functioning.

In 2008, Engel-Yeger (n_{VI} = 22, n_{WO} = 25, N = 47; 4-7 years) found that youth with amblyopia scored significantly lower on static balance, dynamic balance (excluding jumping), mean dynamic balance score, total mean balance scores. Further, parents completed the Child's Balance Performance in Daily Life questionnaire (which had previously been found to be internally consistent), a survey which had been composed for the study. Using sensory processing theoretical models, the developed questionnaire contained "18 items describing everyday situations performed inside or outside the home that reflect the child's balance and posture abilities, as well as his/her intolerance or hypersensitivity to movement" (Engel-Yeger, 2008, p. 245). Significant correlations between the children's mean MABC balance scores and the parents Child's Balance Performance in Daily Life responses were:

(a) Does your child avoid swinging?

(b) Does your child enjoy somersaults like tumbling?

(c) Does your child lose balance after bending down?

(d) Does your child tend to lean on walls?

Houwen et al. (2008, n_{VI} = 48, n_{WO} = 48, N = 96; 7-10 years) investigated balance in youth with VIs. According to Houwen et al. (2009b), this study scored the highest in quality (i.e., 12 out of 16) out of 26 reviewed, motor skill performance articles completed in youth with VIs. According to the author's findings, youth with severe and moderate VIs 7-10 years of age scored significantly worse at static and dynamic when compared to those without VIs. However, there were not statistically significant difference between those with severe and moderate VIs regarding balance performance. In describing these findings, Houwen et al. (2008, p. 143) elaborate:

> For static balance, it has been reported that visual information plays an important role as it specifies body position, whereas dynamic balance during fast movement is expected to depend more on the ability to rapidly transform perturbations of proprioceptive or vestibular origin into proper motor responses (Hatzitaki, Zisi, Kollias, & Kioumourtzoglou, 2002; Riach & Hayes, 1987). The results in the present study correspond to these findings, as no significant difference was found between children with VI and children without VI for dynamic balance fast. Bouchard (1996) also reported that static balance was more affected than dynamic balance in children with VI.

***Results based on other clinical motor assessments*.** In an extremely thorough, albeit low powered study, Brambring (2006a, N_{VI} = 4; 4-6 years) examined the longitudinal motor skill development of a small group of congenitally blind youth. Using (a) developmental data based on youth who are blind with the Entwicklungsbeobachtung und Entwicklungsforderung blinder Klein und Vorschulkinder (Brambring, 1999; Brambring, 2006b [English version]) and (b) four standardized developmental assessments used with youth without VIs (Bayley Scales of Infant Development, Bailey, 1969; Denver Developmental Screening Test [German version], Flehmig, Schloon, Uhde, & von Bernuth, 1973; Griffiths Developmental Scales [German version], Brandt, 1983;

Entwicklungskontrolle ftir Krippenkinder, Zwiener & Schmidt-Kolmer, 1982) the author examined the motor development of youth with blindness using 29 purposefully selected gross motor skills items.

For static balance, stands confidently and stands for a short time were assessed. For dynamic balance, stands on one foot (assisted), stands on one foot (unassisted), walks along a line, bends down and picks up an object, and hops on the spot with both legs were assessed. Results showed that youth who were blind "had much lower developmental divergences on static balance than on dynamic balance" (Brambring, 2006a, p. 630) leading the author to suggest that dynamic balance may depend more on visual control during the early years. The finding that dynamic balance is worse than static balance in youth with VIs is in direct opposition to previously literature (Bouchard, 1996; Häkkinen al., 2002; Houwen et al., 2008). However, it is likely that this finding is age-related as this study only examined ages 4-6 years. Youth who are blind appear to motorically compensate as they age either due to verbal or physical guidance (Brambring, 2006a) and it has been purported that vision is a dominant sense for motor development until the age of 6 (Assaiante &, Amblard, 1995).

A second study published by Navarro et al. (2004, $n_{\mathrm{VI}} = 20$, $n_{\mathrm{WO}} = 20$, $N = 40$; 7 years) assessed balance using the Exame Neurológico Evolutivo [Neurological Evolution Examination] (Lefèvre, 1976). Static balance was assessed by qualitative success/failure evaluations with feet together, on one foot, with knees bent at 90 degrees, in a crouched position, and balancing a ruler on the index finger. Dynamic balance was assessed by asking the participants to jump vertically with maximal effort and clap twice before landing. Regarding static and dynamic balance, the only assessment that was statistically significant to participants who were sighted was the static balance test of balancing with knees bent at a 90-degree angle based on the failure/success of keeping the knees bent at 90 degrees. However, participants with VIs did descriptively perform worse at the one foot and jump/clap tasks.

Results based on stabiliometry. Several balance/VI researchers have used a stabiliometer (Gipsman, 1981; Haibach et al., 2011; Johnson-Kraemer et al., 1992; Ribadi et al., 1987). A stabiliometer is a dynamic balance apparatus (Dvir & Trousil, 1982) which has historically been used in motor behavior settings and/or laboratories. Gipsman (1981, $n_{\text{VI}} = 24$, $n_{\text{WO}} = 24$, $N = 48$; 8-14 years) examined balance performance on a stabiliometer and described a balance-related motor performance hierarchy based on age and vision. In 12-14-year olds, balance performance followed the following hierarchy (ordered best to worst): sighted, totally blind, blindfolded legally blind, and sighted blindfolded. This finding was later confirmed by Ribadi et al. (1987) in a slightly older age band. In a younger group of 8-10-year olds, youth without VIs performed best, however, the same hierarchy was not reproduced. It was also found that older youth with VIs performed better than younger youth with VIs, establishing that age may be an important factor for balance performance.

Ribadi et al. (1987, $n_{\text{VI}} = 17$, $n_{\text{WO}} = 34$, $N = 54$; 14-17 years) used a stabiliometer as well as a single leg stance test (i.e., stork stand). Sex was not found to effect balance performance which have been supported by Rutkowska et al. (2015), Pereira (1990), and Leonard (1969), however, similar to Gipsman (1981), a balance hierarchy of dynamic (i.e., stabiliometer) balance performance decreasing from participants without VIs, to youth with VIs, to youth without VIs who were blindfolded was noted. A statistically significant difference was not found between youth with VIs and youth without VIs who were blindfolded on static (i.e., stork stand) balance. However, youth with VIs performed significantly better than youth without VIs who were blindfolded on the dynamic task. It was concluded that youth with VIs have adapted (to some level) to offset their lack of vision while the youth without VIs who were blindfolded. Implications of this are elucidated by Ribadi et al. (1987, p. 224).

> The sighted blindfolded subjects had no opportunity to adapt or to develop hierarchal strategies for postural control, and therefore performed poorly on dynamic balance. This finding further supports the essential role of vision to the balance act. Obviously, experience alone cannot compensate for loss of sight when it comes to performing dynamic balance. A certain amount of learning must take place to assist unsighted individuals in overcoming the various perturbations in their environments.

This finding is also contradictory to the findings of Bouchard (1996) and Houwen et al. (2008) in which static balance was not impaired in youth with VIs but does match Brambring's (2006a) findings which were found in youth aged 4-6.

One interesting finding occurred in the study completed by Johnson-Kraemer et al. (1992, $n_{\mathrm{VI}} = 7$, $n_{\mathrm{WO\text{-}1}} = 9$, $n_{\mathrm{WO\text{-}2}} = 9$, $N = 25$; 9-14 years). Using a stabiliometer, no significant error scores were found between participants who were sighted and participants with VIs who were blindfolded. However, the participants without VIs who were blindfolded did have more errors than the other two groups. This evidence supported that participants with VIs were more efficient than those without VIs who were occluded—again highlighting a balance performance hierarchy (Gipsman, 1981; Ribadi et al., 1987). Further, boys were found to perform better than girls challenging the findings of Pereira (1990) and Ribadi et al. (1987).

A more modern examination of balance performance which utilized a stabiliometer and a force plate (i.e., static balance; center of pressure) was conducted by Haibach et al. (2011, n_{VI} = 22, n_{WO} = 22, N = 44; 12-17 years). Haibach and colleagues found that typically, degree of VI and experience with vision were significant factors of balance and postural performance. Those with VI had poorer balance, increased variability, and (anecdotally) appeared to need increased usage of the upper body (i.e., appeared to freeze their degrees of freedom more) compared to those without VIs. Further, balance self-efficacy was examined with the ABC Scale and it was found that self-efficacy was associated with the more difficult balance tasks completed on the stabiliometer. However, self-reported balance self-efficacy was not statistically different between groups, although there was a trend toward higher ratings in participants without VIs. Further, ratings within participants with VIs were more varied compared to those without VIs. The most correlated scenarios (to the physical balance assessments) within the ABC Scales in participants with VIs were: (a) walking in a crowd/bumped, (b) stand on chair to reach, and (c) walk on icy sidewalks (i.e., more challenging scenarios within the ABC Scale).

***Results based on motor educability tests*.** Historically, motor educability tests were very popular in physical education around the late 1920s until the mid-1950s. Stunt-type motor educability assessments mainly comprised of gymnastics/stunt/balance tasks (Brace, 1927; Johnson, 1932; McCloy, 1934; McCloy, 1937; Metheny, 1938) were common assessments until the transition towards sport-type educability emerged (Adams, 1954). Therefore, it is not surprising decalages ago, researchers who investigated balance utilized these assessments. The most significant sample ever assessed regarding balance and youth with VIs was conducted by Buell (1950, N_{VI} = 865; “well distributed” years). Buell (1950) used the Iowa Brace Test (which included static balance). However, the specific results of the static balance assessments were not provided. Overall, Buell (1950) concluded that youth with VIs were lagging in motor educability and that performance was better but not markedly different between those with severe and moderate VIs. Likewise, Case et al. (1973, n_{VI} = 30, n_{WO} = 30, n_{HI} = 30, N = 90; 16-18 years) examined motor educability using 11 of the 21 stunts from the Iowa Brace Test of Motor Educability between youth with and without VIs as well as youth with hearing impairments. Youth with VIs were not found to have statistically different balance capacity when compared to those without VIs or with hearing impairments. However, anecdotally, youth with VIs were described as having increased levels of apprehension about falling,

***Results based on practical balance assessments*.** Finally, some researchers have used more general and practical assessments (e.g., stork/flamingo standing, balance beams/boards). Leonard (1969, n_{VI} = 101, n_{WO} = 114, N = 215; 12-20 years) compared balance abilities between individuals with and without VIs using a balance board and balance beam task. Those with VIs required a wider beam for static balancing than those without VIs, however, no relationship between degree of residual vision and static performance was found. Further, static balance performance between boys and girls with VIs was not statistically different. However, dynamic balance was related to level of vision. These findings again add conflicting evidence about whether static or dynamic tasks are most influence by a lack of vision. Interestingly, low static balance scores predicted poor dynamic balance; however, high static scores did not guarantee high dynamic scores. There was a clear difference in performance favoring those without VIs overall.

Pereira (1990, n_{VI} = 67, n_{WO} = 150, N = 217; 6-13 years) used an adaptation of Leonard's balance test (Leonard, 1969) in which better balance performance differences between individuals with and without VIs appeared to be related to visual acuity while age and sex did not seem to influence balance. Again, these results are consistent with the mixed findings from other research regarding the impact of age and sex on balance performance in those with VIs. In a more recent study, Häkkinen et al. (2006, n_{VI} = 16, n_{WO} = 17, N = 33; 9-18 years) utilized the modified flamingo balance test on a raised beam with eyes open and shaded with blackout sunglasses. In younger and older participants, balance performance was significantly different in favor of those without VIs. However, when the vision of the participants without VIs was blocked, the differences between those with and without VIs disappeared. Again, providing evidence of a balance-based motor hierarchy.

From balance to fundamental motor skills. Balance is often emphasized for its important role in locomotion (Skaggs & Hopper, 1996). According to unpublished raw data by Rosen (1989), dynamic balance was impaired in participants with VIs (6-18 years). Per Rosen (1989), impaired balance measures correlated with the presence of selected immature gait characteristics (e.g., out-toeing, short-stride lengths). As such, it has been suggested that individuals with VIs make adaptations in mobility to maintain stability and/or safety (Horvat et al., 2003; Ray, Horvat, Williams, & Blasch, 2007).

Further, as Ribadi et al. (1987, p. 220) concludes, “one of the most important skills associated with the successful acquisition of motor proficiency is balance.” However, controversy over this topic exists. According to Ulrich and Ulrich (1985), although to role of balance is logically appealing, strong empirical evidence of the relationships between balance and more advanced motor skills has been deficient. This belief may have led the creators of the TGMD-3 (Ulrich, 2000; Webster & Ulrich, 2017), one of the most popular motor development assessment tools in the United States, to not assess balance/stability skills. Origins of this decision may trace back to Ulrich and Ulrich (1985) where it was found that balance measures from the BOT (Bruininks, 1978) and stages of development for six fundamental motor skills (Seefeldt & Haubenstricker, 1974-1976) were not convincing.

A multivariate analysis of covariance (controlling age as the covariate) was calculated to examine the main effect of balance on fundamental motor skills and the model was found to be significant (Wilk’s Λ (balance) = 0.699; $F_{7,63} = 3.87$, $p < 0.05$). Univariate analysis showed that balance performance was significantly associated with hopping with either foot, jumping, and striking ($p < 0.05$; $R^2 = 0.05 - 0.17$) but not with skipping, throwing, or kicking. Based on static and dynamic balance tasks, static balance scores significantly related to hopping on the preferred foot and striking, dynamic balance with jumping, and both static/dynamic balance with hopping on the nonpreferred foot. Yet, based on the small proportion of the variance from the significant balance relationships (i.e., $R^2 = 05 - 0.17$), it was concluded that balance (likely) has low practical significance. However, Ulrich and Ulrich (1985) do concede that both assessments may have been too specific and elucidated that correlational balance research can be a tangled enterprise (Drowatzky & Zuccato, 1967; Hempel & Fleishman, 1955; Tsigilis et al., 2001). Therefore, additional conceptualizations and analyses of balance in fundamental motor skills is warranted. Particularly as modern motor skill batteries show balance/stability as being related to locomotion and object control skills (Luz et al., 2016; Rudd et al., 2015).

Summary. A lack of vision has historically been linked with balance impairments, especially during early development (i.e., birth-six years). It has been suggested that after the age of six years, most youth with VIs appear to compensate and 'catch up' motorically (potentially due to maturation, verbal or physical guidance), albeit to varying degrees. While these adaptations appear to occur with rudimentary motor skills, in general, evidence suggests (fundamental) motor skill competence and/or proficiency does not compensate to the same level when compared to those without VIs. Research has shown that youth with VIs tend to perform worse at balance when compared to those without VIs. Findings tend to highlight that those with lower levels of vision (i.e., severe blindness) have the largest balance deficits, however, these findings are not universal. Regarding static and dynamic balance, equivocal results exists. Therefore, it cannot be concluded that youth with VIs are more prone to static or dynamic balance issues.

Most studies have not found sex effects regarding balance performance while the opposite appeared to be true regarding age. Also, several researchers have provided potential evidence of a visuo-perceptual hierarchy regarding balance performance (best to worst): youth without VIs, youth with VIs, youth without VIs who have their vision occluded—highlighting that those with VIs are able to adapt (to some level) to their lack of vision during certain balance tasks. Last, balance performance may be more related to facilitators/barriers to movement as opposed to being explained purely by an impaired visuo-perceptual system (i.e., experience versus physiology). A variety of assessments, sample sizes, and contexts have been used for balance research in youth with VIs. Crucially, most studies have lacked empirical rigor (Houwen et al., 2009b), application to the real world, and/or utility for practitioners. Further, the predictive validity (i.e., what are the implications of a balance assessment for the future) of balance assessments have been grossly ignored in youth with VIs.

Table 2.1

Measures of Visual Function

Function	Description
Visual acuity	Ability to resolve images of various sizes at fixed distances
Visual field sensitivity	Ability to detect objects of various sizes within visual space
Contrast sensitivity	Ability to detect images against decreasingly contrasting backgrounds
Visual processing speeds	Time to complete visual tasks
Dark adaptation	Ability to adjust to low levels of illumination

Note. Adapted from the National Academies of Sciences, Engineering, and Medicine (2016).

Table 2.2

Anatomy of the Eye and Associated VIs

Ocular Structure	Associated VIs	Conditions Related to Ocular Structure
Cornea	Reduce acuity and contrast, glare, light sensitivity	Corneal scar, lattice corneal dystrophy
Iris (thinning or absent)	Light sensitivity	Aniridia, albinism
Lens	Reduced acuity and contrast, glare	Cataract
Retina		
Cone photoreceptors	Reduced acuity, reduced color discrimination, light sensitivity	Cone dystrophy, achromatopsia
Rod photoreceptors	Reduced night vision, loss of peripheral visual field	Rod dystrophy (retinitis pigmentosa)
Foveal hypoplasia	Reduced visual acuity	Albinism, aniridia
Macula (lesion of)	Reduced visual acuity, eccentric viewing	Ocular histoplasmosis, age-related macular degeneration
Optic nerve	Reduced visual acuity and contrast, visual field defects	Hereditary optic atrophy, glaucoma

Note. Adapted from Schwartz (2010).

Table 2.3

Childhood Congenital and Acquired Diseases and Conditions Causing VIs

Congenital	Acquired
Achromatopsia, anterior segment dysgenesis, aniridia (Axenfeld-Reiger syndrome), albinism, cataract, coloboma, congenital infection, congenital stationary night blindness, corneal opacity, cortical VI, familial exudative vitreoretinopathy, glaucoma, nystagmus, optic atrophy, optic nerve hypoplasia, persistent hyperplastic primary vitreous, refractive error, retinal dystrophy, Stickler syndrome, strabismus	Amblyopia, age-related macular generation, cataract, corneal opacity (scar), diabetic retinopathy, ectopia lentis, glaucoma, optic atrophy, refractive error, retinal detachment, retinal dystrophy, retinopathy of prematurity, Stargardt disease, strabismus, uveitis

Note. Adapted from Schwartz (2010).

Table 2.4

World Health Organization VI Classifications

Category	Presenting distance visual acuity	
	Worse than	Equal to or better than
0 Mild or no VI		6/18 3/10 (0.3) 20/70
1 Moderate VI	6/18 3/10 (0.3) 20/70	6/60 1/10 (0.1) 20/200
2 Severe VI	6/60 1/10 (0.1) 20/200	3/60 1/20 (0.05) 20/400
3 Blindness	3/60 1/20 (0.05) 20/400	1/60* 1/50 (0.02) 5/300 (20/1200)
4 Blindness	1/60* 1/50 (0.02) 5/300 (20/1200)	Light perception
5 Blindness	No light perception	
9	Undetermined or unspecified	

Note: Adapted from the World Health Organization (2016). * = or counts fingers at 1 meter.

Table 2.5

Quality Ratings of a Sample of Studies Involving Balance in Youth with VIs

Citation	Quality Rating
Aki et al. (2007)	5
Bouchard & Tetreault (2000)	9
Caputo et al. (2007)	10
Engel-Yeger (2008)	8
Gipsman (1981)	6
Häkkinen et al. (2006)	10
Houwen et al. (2008)	12
Johnson-Kraemer et al. (1992)	5
Leonard (1969)	3
Pereira (1990)	5
Ribadi et al. (1987)	7
Schneekloth (1989)	3
Wyver & Livesey (2003)	8
Average	7

Note. Adapted from Houwen et al. (2009b). Maximum score = 16.

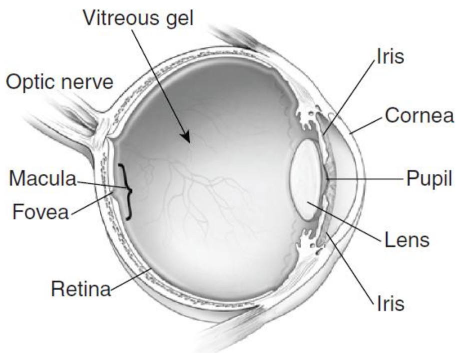

Figure 2.1 Diagram of the eye from the National Eye Institute (n.d.).

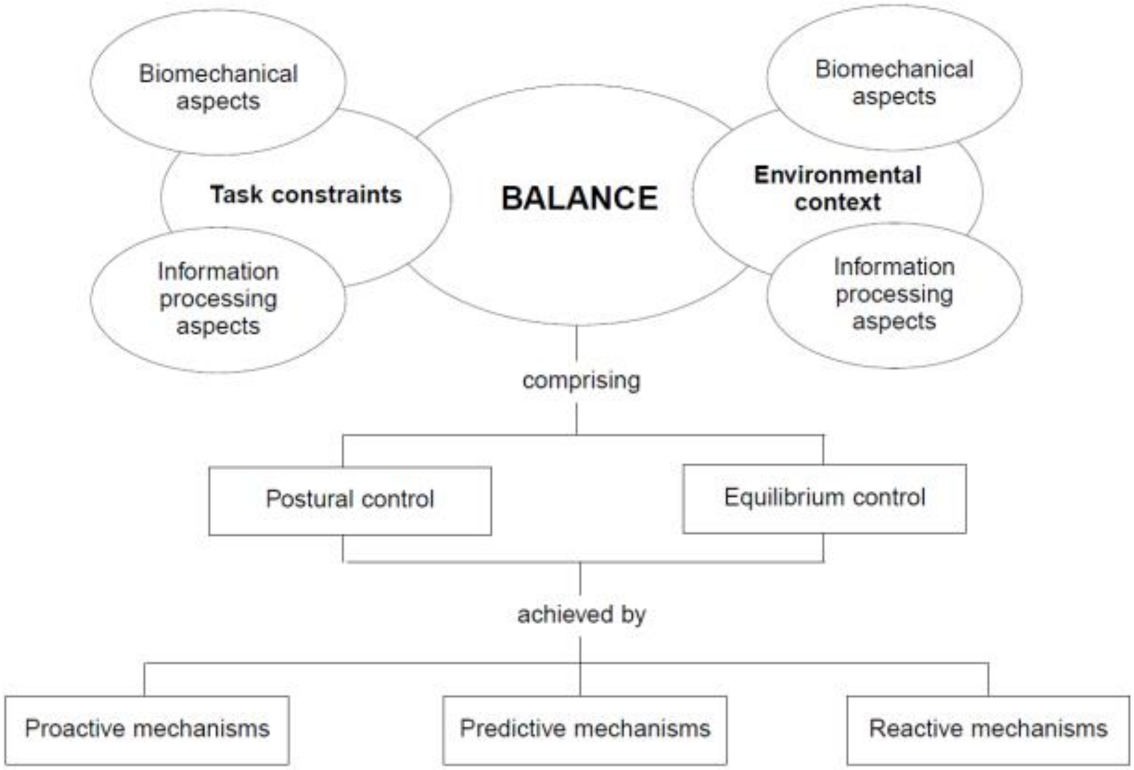

Figure 2.2 Huxham and colleagues' (2001) determinants of functional balance.

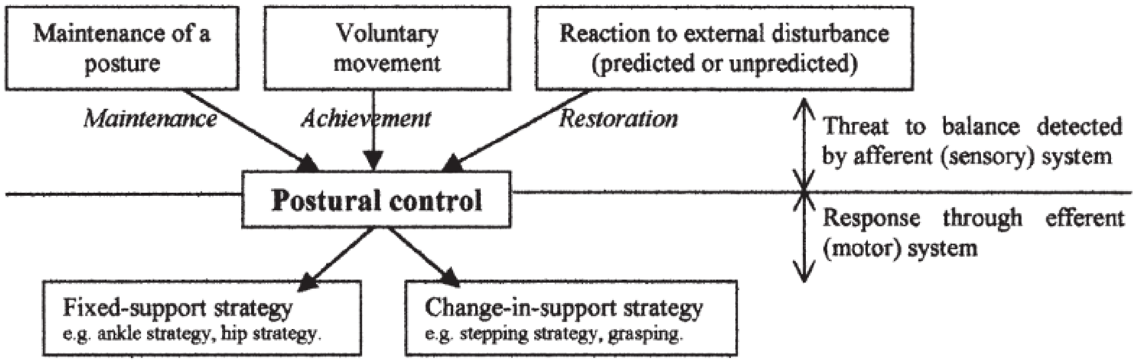

Figure 2.3 Pollock and colleagues' (2000) postural control strategies.

CHAPTER 3: STUDY 1

CONSTRUCT AND CONVERGENT VALIDITY OF THE BRIEF-BESTEST IN YOUTH WITH VISUAL IMPAIRMENTS

Introduction

Youth with VIs have been found to balance deficits when compared to peers without VIs (Bouchard & Tetreault, 2000; Engel-Yeger, 2008; Gipsman, 1981; Häkkinen et al., 2006; Houwen et al., 2008; Leonard, 1969; Navarro et al., 2004; Pereira, 1990; Ribadi et al., 1987; Uysal & Düger, 2011; Wyver & Livesey, 2003). However, serious concerns over the inconsistences and rigors of previous balance investigations in youth with VIs have been raised (Houwen et al., 2009b). Further, Overlock and Yun (2004) suggested that balance assessment has been plagued by methodological/assessment issues and underdeveloped conceptualizations of balance.

Assessments may investigate static and/or dynamic balance, may be more practical or more laboratory-based, or may conceptualize balance in a very specific (e.g., walking a balance beam) or general way. While some assessments may have a variety of activities (e.g., perturbed and non-perturbed), most assessments (if not all) lack environmental, biomechanical, and/or cognitive considerations, or do not adequately reproduce proactive, predictive, and/or reactive balance mechanisms in authentic and dynamic settings (Huxham et al., 2001). As Reed (1989, p. 6) noted, "a primary function of posture is the integration of movements into coordinated action sequences. Such phenomena simply do not emerge in experimental paradigms devoted to isolated movements under constrained conditions." Therefore, more empirically-authentic balance assessments are needed.

Compared to traditional balance assessments, the Brief-Balance Evaluation Systems Test (Brief-BESTest; Padgett et al., 2012) may be a contemporary and viable alternative. The Brief-BESTest is a multifaceted balance battery that is practitioner-friendly, inexpensive, and can be administered quickly. Further, the Brief-BESTest utilizes a 'systems-based' framework (Horak et al., 2009; Sibley et al., 2015) allowing for the multidimensional analysis of balance performance by considering dynamic sensorimotor interactions and contextual factors (Horak, 2006).

The reliability and validity of Brief-BESTest scores have been examined in adult/neurological populations but not in youth with VIs (Jácome et al., 2016; O'Hoski et al., 2014; Padgett et al., 2012). Prior to the adoption of an assessment, scores from specific populations or contexts should be interpreted and evaluated (American Educational Research Association, American Psychological Association, & the National Council on Measurement in Education, 2014; Cronbach & Meehl, 1955). Therefore, Brief-BESTest scores in youth with VIs must be psychometrically vetted before the Brief-BESTest can be adopted by practitioners and researchers alike.

If Brief-BESTest scores are found to perform well in youth with VIs, the Brief-BESTest could: (a) be used to assess balance, (b) provide detailed balance profiles, (c) be correlated to relatable variables of interest (e.g., psychomotor objectives, physical activity measures, health indicators), and (d) lead to targeted balance interventions in youth with VIs. Thus, the purpose of this study was to examine the construct and convergent validity of Brief-BESTest scores in youth with VIs. Using scores from youth with VIs, it was hypothesized that the psychometric properties of the Brief-BESTest would be acceptable, that the Brief-BESTest items would load as a one-factor latent model using confirmatory factor analysis (CFA), and that total Brief-BESTest scores would converge (i.e., significantly correlate; $p < .05$) with total scores from other balance assessments.

Methods

Participants and Setting

Using convenience sampling, youth with visual impairments (N = 101) were recruited from Camp Abilities Brockport (NY) Saratoga Springs (NY), and Starke (FL) as well as the Governor Morehead School for the Blind (NC). Descriptive information for the sample was as follows: M_{age} = 13.91 years ± 2.82, $M_{maturityoffset}$ = .38 ± 2.16 years, M_{height} = 1.55 meters (m) ± .12, M_{weight} = 58.22 kilograms (kg) ± 21.87, M_{BMI} = 23.52 kg/m^2 ± 6.63, and $M_{BMI\%}$ = 69.52 ± 24.06. Concerning visual classification, 8% (n = 8) were B4, 33% (n = 33) were B3, 28% (n = 28) were B2, and 32% (n = 32) were B1. Fifty-six percent of the participants were boys (n = 57) while 38% (n = 38) of the sample had a comorbidity. Regarding race, 12% were Black (n = 12), 17% were Other (n = 17), and 70% were White (n = 71). Fifty-three percent, 42%, and 5% of the sample attended public, schools for the blind, and private schools, respectively.

Instrumentation

Demographics. A self-report demographic and visual information questionnaire was completed by the parent/guardian of each participant while the participant was present.

Anthropometrics. Standing height as well as weight were assessed while barefoot. Standing height and weight were used to determine BMI percentiles (United

States Department of Health and Human Services, 2010). Predicted maturity offset (i.e., years before or after peak height velocity [PHV]) was estimated with the Moore-1 sex-specific equations (Moore et al., 2015). Subsequently, an estimate of age at PHV was calculated (i.e., predicted maturity offset - age; Mirwald, Baxter-Jones, Bailey, & Beunen, 2002).

Brief-BESTest. The Brief-BESTest was used to assess six balance systems (i.e., eight items). The Brief-BESTest has been found to be reliable and valid in separate populations (Jácome et al., 2016; O'Hoski, Sibley, Brooks, & Beauchamp, 2015; Padgett et al., 2012). The six systems and the eight respective items are as follows: (a) biomechanical constraints—hip/trunk lateral strength (Hip), (b) stability limits—functional reach forward (Reach), (c) transitions—standing on one leg on each side (Single-R; Single-L) (d) reactive—lateral compensatory stepping on each side (Fall-R; Fall-L), (e) sensory orientation—standing with eyes closed on foam (Foam), and (f) stability in gait—timed "up and go" (UpGo). Participants were digitally recorded performing the Brief-BESTest and retroactively scored using an ordinal scale (i.e., 0-3) for each item. Each of the eight test items were combined to create a composite score between 0 and 24. Higher scores represented better balance performance. Total test time ranged around 10 minutes per participant.

Postural sway. Postural sway was examined via bipedal quiet stance. Historically performed on a force plate in laboratory settings, the quantification of sway on force plates has been considered the 'gold standard' of balance/postural assessment (Haas & Burden, 2000); however, force plates are costly and cumbersome. In recent years, a valid, relatively less expensive (when compared to a force plate), and more portable alternative has grown in prominence in the field of posture and balance: inertial measurement units. Using an algorithm, inertial measurement units estimate movement by fusing accelerometer, gyroscope, and magnetometer data (Brunetti, Moreno, Ruiz, Rocon, & Pons, 2006; Mayagoitia, Lotters, Veltink, & Hermens, 2002; Neville, Ludlow, & Rieger, 2015; Seimetz, Tan, Katayama, & Lockhart, 2012).

With feet positioned using a standardized foot plate, participants stood quietly with arms on their hips, two meters from a neutral colored wall with eyes open for 30 seconds while visually fixating on a three-centimeter diameter black dot (i.e., external focus) directly in-front of their eyes (Maeda, Nakamura, Otomo, Higuchi, & Motohashi, 1998) while wearing an advanced wearable Opal sensor (APDM, Inc., Portland, OR) positioned on the lumbar spine (L5) with an adjustable elastic belt. A three-centimeter diameter dot was utilized as visual targets have been shown to reduce postural sway and saccades in youth (Riach & Starkes, 1989). Irrespective of whether or not the participant was able to see the dot, they were instructed to focus on the target/maintain a horizontal gaze at all times and to "stay as still as a statue" for the duration of each trial.

The 95% ellipse sway area (m^2/s^4) defined as "the area of an ellipse covering 95% of the sway angle in both the coronal and sagittal planes" (APDM, Inc., 2015) was calculated for each trial. This calculation should not be confused with the 95% confidence ellipse defined by Rocchi and colleagues (2005, p. 169) as "the ellipse that, with the (1 - α)% of probability, contains the center of the points of the sway. In more general terms, a confidence ellipse is a region that covers the center of a sample with a given probability." All trials were quantified using the Mobility Lab software (APDM, Inc., Portland, OR). The average of three trials was used for analysis. As 95% ellipse sway area is a linear function, higher mean sway area represented impaired balance performance (Kirchner, 2013). Total test time ranged around three minutes per participant.

360-degree turn test. The 360-degree turn test is a balance assessment that can be traced back to Tinetti (1986). The 360-degree turn test provided a ratio data point (i.e., turn velocity [degrees/sec]) via an advanced wearable Opal sensor (APDM, Inc., Portland, OR) positioned on the lumbar spine (L5) with an adjustable elastic belt. On the command "go," participants were instructed to complete a full 360-degree turn to a self-selected side. Once they had completed a complete 360-degree circle (as verbally confirmed by the assessor), the participants were then instructed to quickly "go back" 360-degrees (i.e., two consecutive 360-degree turns, one in each direction). Participants were required to "take steps" to complete the assessment and were not permitted to spin/twirl. All trials were quantified using the Mobility Lab software (APDM, Inc., Portland, OR). The average of three trials was used for analysis. Higher mean velocity represented better balance performance. Total test time ranged around one minute per participant.

Anterior Reach Lower Quarter Y-Balance Test. The Anterior Reach Lower Quarter Y-Balance Test (AR-YBT) was used to assess dynamic balance. The full YBT (i.e., anterior, posteromedial, posterolateral reaches) has been found to be reliable and valid in separate populations (Gribble, Kelly, Refshauge, & Hiller, 2013; Plisky, Rauh, Kaminski, & Underwood, 2006; Shaffer et al., 2013). However, pilot testing suggested the posterior reaches were exceedingly difficult for most youth with VIs. Further, assessing all three planes in youth with VIs resulted in large testing times and led to fatigue/frustration in youth with VIs. Therefore, only the AR-YBT was assessed.

While maintaining a single leg stance on a stance platform, participants attempted to maximally reach with the non-stance limb in the anterior direction using the Y-Balance Test Kit (Plisky et al., 2009). Each participant practiced reaching with the left limb in the anterior plane for six trials and then performed three official trials. If a successful trail was not completed after the third official trial, an additional trial was completed. If a participant could not complete a successful trial, they were given a score of zero for that stance/reach combination. The same protocol was then be repeated by reaching with the right limb in the anterior plane.

A trial was discarded if the participant: touched the floor, fell off the stance platform/did not keep their stance leg behind the stance line, kicked or placed their foot on top of the reach indicator, or failed to return the reach foot to the starting position under control. All trials were completed while barefoot. Stance foot and body movement were permitted (e.g., heel raising, unrestricted arm/hand movement) (Plisky et al., 2009). While standing, participant right limb length was measured in centimeters from the anterior superior iliac spine to the most distal portion of the medial malleolus to allow normalization of the reach lengths (i.e., [raw reach distance / right limb length]*100; Plisky et al., 2006).

Minor adaptations were made to the Y-Balance Test Kit/protocol to assist youth with VIs in completing the AR-YBT. First, participants were verbally and tactically guided through the Y-Balance Test Kit by the assessor (e.g., sitting on their knees physically feeling/exploring the kit while being given verbal explanations of the task). A piece of floor tape was rolled into a cylindrical shape and then taped to the stance line on the stance platform (see Figure 3.1). This allowed youth with VIs to tactically identify where their stance foot should be placed at all times. Second, a piece of multi-colored tape was placed on the front-side of the reach platform. The multi-colored tape gave color and pattern contrast to the front side of the reach platform (i.e., the side participants needed to locate and guide forward with their reach foot; see Figure 3.2). If needed, participants were provided with verbal guidance by the assessor during the completion of the AR-YBT trials (e.g., "lower your foot a bit more and bring it forward until you meet the front side of the platform"). It is believed that these adaptations made the YBT more accessible for youth with VIs and did not undermine the underpinnings of the YBT.

Raw maximum scores for each AR stance/reach combination were identified. Each raw maximum score was then normalized to right limb length distance. Both normalized maximum distances were than summed representing a single composite AR score (i.e., maximum normalized left reach + maximum normalized right reach). Composite AR scores were then categorized by quartile (type = 7; 1: < 25^{th}, 2: < 50^{th}, 3: < 75^{th}, 4: ≥ 75^{th}). That is, higher AR-YBT classification represented better balance performance. Total test time ranged from five to 15 minutes per participant.

Activities-specific Balance Confidence Scale. The ABC Scale is a 16-item self-report measure in which participants rate their balance confidence in performing everyday activities. The ABC Scale has been found to be reliable and valid in separate populations (Powell & Myers, 1995; Raad, Moore, Hamby, Rivadelo, & Straube, 2013), has been used in youth (Ilg et al., 2012), and has been purported to have face validity in youth with VIs (Haibach et al., 2011). Responses are based on a rating scale which uses

10% increments (i.e., 0%, 10%, 20%, etc.). Scores range from 0% (i.e., no confidence) to 100% (i.e., complete confidence). For example, "How confident are you that you will not lose your balance or become unsteady when you…walk up and down stairs." The participant thinks and responds "80%." Participants completed the ABC-16 in a face-to-face interview with a member of the research team. The composite score was calculated by summing the percentages of each item and then dividing by the total number of items. Higher mean ABC Scale scores represented higher balance perceptions. Total test time ranged from three to five minutes.

Procedures

Internal Review Board approval was granted by the University of South Carolina for this study. Research sites which agreed to participate in this study included Camp Abilities Brockport (NY), Saratoga (NY), Starke (FL), and the Governor Morehead School for the Blind (NC). At each site, participants were recruited in a face-to-face format where signed parental and/or participant consent and demographic questionnaires were completed. Within the school, data collection occurred after-school during one-hour timeslots during the evening. At Camp Abilities, data collection occurred during one-hour timeslots in the morning or evening. During data collection, participants first completed the ABC Scale and were anthropometrically assessed and then completed the Brief-BESTest, postural sway, 360-degree turn test, and the AR-YBT while barefoot. The Brief-BESTest was digitally recorded and retroactively coded. All data were collected in 2018.

Analysis

Data screening/preparation. All analyses were conducted using R statistical software (R Core Team, 2013). Prior to statistical analyses the aggregated data was assessed for missingness. Percent, patterns, and mechanisms of missingness were found to be satisfactory for imputation (Bennett, 2001; Dong & Peng, 2013; Kang, 2013; Rubin, 1976). Missing cells were imputed using the *missForest* package (Stekhoven & Bühlmann, 2012). Estimated error levels for the imputation were satisfactory (Oba et al., 2003; Stekhoven & Bühlmann, 2012). Following the completion of the imputation, the dataset was screened for normality and outliers to inform subsequent statistical analyses.

Individual Brief-BESTest items, total score, AR-YBT quantile classification, 360-degree turn, postural sway, and ABC Scale were assessed for univariate normality using the Shapiro-Wilk test. All variables of interest were found to be non-normal ($p < .001$) except for the 360-degree turn ($p = .96$). Royston's multivariate normality test confirmed a lack of multivariate normality for the individual Brief-BESTest items ($H = 376.86$, $p < .001$) and the five balance assessments ($H = 125.31$, $p < .001$). Outliers were determined using the 'fence' method (±1.5 * interquartile range; interquartile range = type 7). Five (5.0%; Brief-BESTest), zero (0%; AR-YBT), three (3%; 360-degree turn), 11 (11%; postural sway), and two (2%; ABC Scale) participants were identified as outliers. All outliers were deemed relevant to the sample, therefore, none of the outliers were removed from the dataset.

Descriptives. Measures of central tendency and spread were calculated for all applicable variables.

Internal consistency reliability. Internal consistency (i.e., the interrelatedness of components within a test [Tavakol & Dennick, 2011]) for the individual items of the Brief-BESTest was determined by calculating ordinal omega (Peters, 2018). An internal consistency coefficient of $\geq .70$ but $\leq .90$ was deemed as strong yet non-redundant (Tavakol & Dennick, 2011).

Brief-BESTest inter-item correlations. Zero-order Spearman correlations (ρ) were used to assess the strength and direction of the monotonic relationship between the eight Brief-BESTest item scores. Absolute value two-tailed bivariate coefficients were classified as very strong ($\rho \geq .70$), strong ($.40 \geq \rho \leq .69$), moderate ($.30 \geq \rho \leq .39$), weak ($.20 \geq \rho \leq .29$), or negligible ($.00 \geq \rho \leq .19$) (Dancey & Reidy, 2007). Further, a bias-corrected (i.e., Fisher's Z transform and back transform) average inter-item correlation for all Brief-BESTest items was calculated. Clark and Watson (1995) suggest the average inter-item correlation should fall between .15 and .50, however, for a specific/narrow target construct, $\geq .40$ is desirable.

Exploratory factor analysis. The sample size of this dataset (N = 101) was below a common rule of thumb (i.e., $\geq$ 150-200; Kyriazos, 2018). However, smaller sample sizes can be acceptable for exploratory factor analyses (EFA; de Winter, Dodou, & Wieringa, 2009). Further, with eight items in the Brief-BESTest, the subject-to-variable ratio (i.e., 101:8) equated to 12.63:1 which is larger than the minimum suggested subject-to-variable ratio of ≥10:1 (Costello & Osborne, 2005). Therefore, with caution, it was concluded that the sample size appeared adequate to move forward with the analyses.

Next, the factorability of the matrices was examined. The strengths of the zero-order monotonic relationships proved to be acceptable. Further, the determinant of the matrix (*det* = .04 where <.00001 = multicollinearity issues, Field 2000), Bartlett's test of sphericity (p < .001 where p > 0.05 = items are not inter-correlated, Hair, Black, & Babin, 2010), and the Kaiser-Meyer-Olkin test of sampling adequacy (KMO = .79 where < .60 = inadequate sampling adequacy, Hair et al., 2010) were run. All three results confirmed it was acceptable to proceed with the EFA.

For extraction, factor analysis (as opposed to principal component analysis) was used. Factor analysis only assesses shared variance (i.e., accounts for error), and therefore, it is more likely to avoid over-inflation of estimates. Because the data were non-normal, Minimum Residual was selected as the preferred factor extraction method (Zygmont & Smith, 2014). It was believed that factors would correlate to some degree, therefore, oblique oblimin rotation was selected. Oblique rotation takes shared variance between the factors into account (i.e., accounts for error) and the degree of correlation between the factors.

Next, the number of factors to retain was examined. Based on a traditional scree plot (i.e., a visual method used to separate trivial and nontrivial factors), the "break in the elbow" occurred at two factors, however, the second factor had an eigenvalue < 1. According to the Guttman-Kaiser rule (i.e., that eigenvalues should be > 1), one factor may be appropriate. However, the Guttman-Kaiser criterion has been criticized in recent decades (Nunnally & Bernstein, 1994). Using more modern methods which are superior to the traditional scree plot (i.e., statistics-based; more likely to not over/under-estimate), a Very Simple Structure (VSS) analysis achieved a maximum complexity with one factor (.83), while Velicer's minimum average partial (MAP) test achieved the minimum squared average partial correlation of .073 with two factors (suggesting the retention of two factors), however, the MAP for one factor was marginally larger (.077). Last, a modified Horn's parallel analysis (*percentile* = 95; Glorfeld, 1995) using common factor analysis suggested the retainment of one factor.

To determine the factor structure of the Brief-BESTest items without imposing a preconceived structure (Child, 2006), both a one- and two-factor EFA model using Minimum Residual factor extraction and oblique oblimin rotation were run. To determine the optimal number of factors, the preferred criteria were: item communalities (h^2) ≥ .40, at least three strong loadings per factor ≥ .50, and the avoidance of cross-loadings (i.e., items should not load ≥ .32 on more than one factor or be within .20 of the items primary factor loading) (Costello & Osborne, 2005; Matsunaga, 2010).

Confirmatory factor analysis. Next, a CFA was implemented to investigate the construct validity of the Brief-BESTest items at the latent level. Construct validity can be defined as "representing the correspondence between a construct (conceptual definition of a variable) and the operational procedure to measure or manipulate that construct" (Schwab, 1980, p. 5). Data were estimated using the mean and variance-adjusted weighted least squares (WLSMV) procedure (Li, 2016; Natesan, 2015). The WLSMV is a robust estimator which does not assume normally distributed variables and provides the best option for modelling categorical or ordered data (Brown, 2006).

Latent factors do not have a scale, therefore, the first item (i.e., UpGo) for the latent variable (i.e., balance) was set to 1.0 for the WLSMV estimates. Robust and diagonally weighted least squares (DWLS) values were calculated; however, robust values were utilized for interpretation of the model. Global and local fit indices (Kline, 2016; Schweizer & DiStefano, 2016) were used to appropriately detail model performance (Jackson, Gillaspy, & Purc-Stephenson, 2009). Global fit indices (i.e., heuristics for overall fit of a model) selected for analyses included the chi-square exact fit test (χ^2), the comparative fit index (CFI), the Tucker-Lewis index (TLI), standardized root mean square residual (SRMR), and root mean squared error of approximation (RMSEA).

The χ^2 test of model fit is a conventional null hypothesis significance test that assesses exact fit between the model and the model reproduced by the data. To pass the χ^2 test, retention of the *null* hypothesis was required. The CFI determines whether the hypothesized model is superior to the baseline (i.e., null) model. The TLI is similar to the CFI and is also an incremental test. It was recommended that CFI and TLI values be $\geq .95$. For SRMR, standardized differences between observed and predicted correlations were calculated. SRMR is a badness-of-fit index were values $\leq .08$ were viewed as acceptable. Finally, RMSEA estimates the discrepancy between the population covariance matrix and the reproduced covariance matrix. Like SRMR, RMSEA also examines lack-of-fit were values $\leq .06$ were viewed as satisfactory.

For local fit (i.e., heuristics for assessing individual components of a model), standardized parameter estimates, standard errors, R^2 values, polychoric residual correlations, z-scores, and modification indices were examined. Good local fit was indicated by (a) standardized parameter estimates that had uniformity within each factor and were significant to the model (i.e., large z-values, $p \leq .05$), (b) standard errors $\leq .10$, (c) R^2 values $\geq .10$, and (d) polychoric residual correlations $\leq .10$.

Modification indices were calculated to determine significant paths not included in the original congeneric model and were termed significant if ≥ 3.84 (i.e., the critical value of χ^2 at $p \leq .05$, $df = 1$). To add strength to the results, two competing theoretically-driven models were examined. Following the theory that all of the Brief-BESTest items would load as a single balance construct, a one-factor model was investigated. Likewise, a model using two factors (defined as dynamic and static) was examined. Based on a task analysis, the authors defined the Brief-BESTest items as predominately dynamic or static balance tasks. Within the two-factor model, the UpGo, Fall-R, Fall-L, and the Reach items were identified as dynamic tasks while Foam, Single-R, Single-L, and the Hip items were identified as static balance tasks. All models were required to be over-identified (i.e., $df > 0$).

Convergent validity. "Convergent validity reflects the extent to which two measures capture a common construct" (Carlson & Herdman, 2012, p. 18). Zero-order Spearman correlations (ρ) were used to assess the strength and direction of the monotonic relationship between the total scores of five balance tests. Absolute value two-tailed bivariate coefficients were classified as very strong ($\geq .70$), strong ($.40 \geq \rho \leq .69$), moderate ($.30 \geq \rho \leq .39$), weak ($.20 \geq \rho \leq .29$), or negligible ($.00 \geq \rho \leq .19$) (Dancey & Reidy, 2004). Further, a bias-corrected (i.e., Fisher's *Z* transform and back transform) average inter-item correlation for all total scores was calculated. Clark and Watson (1995) suggest the average inter-item correlation should fall between .15 and .50, however, for a specific/narrow target construct, $\geq .40$ was desirable.

Results

Descriptive results for the Brief-BESTest can be found in Table 3.1. The ordinal omega for the Brief-BESTest items was .87 (95% CI = .83, .91) highlighting strong internal consistency between the Brief-BESTest items (Tavakol & Dennick, 2011). Zero-order Spearman inter-item correlations for the Brief-BESTest items ranged from .18 (i.e., UpGo/Foam) to .73 (R-Fall/L-Fall; Single-R/Single-L). Twenty-seven of the 28 correlations were statistically significant ($p < .05$; see Table 3.2). Using Fisher's transformation, the average bias-corrected inter-item correlation (i.e., the average correlation of Table 3.2) was .41 suggesting that the Brief-BESTest items were measuring a specific/narrow construct (Clark & Watson, 1995). Most of the associations between the Brief-BESTest items were moderate-to-strong in magnitude except for several of the correlations concerning the Foam item. The Foam item was negatively skewed (-3.60) and leptokurtic (12.80) suggesting the Foam item was not particularly challenging to most youth with VIs (i.e., ceiling effect).

Based on the Minimum Residual oblimin EFA, the one-factor model performed relatively well as seven out of eight Brief-BESTest items presented with standardized loadings ≥ .50 while five out of eight item communalities (h^2) were ≥ .40. The cross-loading criterion was irrelevant for this analysis as the model was a single-factor solution. The two-factor model had six primary factor loadings (versus seven) that were ≥ .50 and also had five item communalities that were ≥ .40. The two-factor model had two cross-loading items—one was within .20 of the items primary factor loading (i.e., Foam) while one item loaded ≥ .32 on both factors (i.e., Reach). As such, the stronger one-factor solution was retained. Within the one-factor model, the Foam item performed the worst (i.e., loading = .48, communality = .23) while both the Hip (.38) and UpGo (.33) communalities were low. This was likely caused by the smattering of negligible, weak, and moderate correlations found in the zero-order Spearman correlation matrix between the Foam, Hip, and UpGo items. Results of the one-factor EFA can be found in Table 3.3.

For the WLSMV-estimated CFA analyses, the initial variance-covariance matrix did not present as positive definite (i.e., the smallest eigenvalue [1.470559e-17] was close to zero). A variance inflation factor (VIF) analysis highlighted that the Fall-R and Fall-L items had VIFs of 4.1 and 4.0, respectively. VIFs of ≈ 4-5 can be a nuisance, while VIFs ≥ 10 denote serious multicollinearity. However, VIF cutoff recommendations vary (Vatcheva, Lee, McCormick, & Rahbar, 2016). Two supplementary CFAs were run, one without Fall-R, and one without Fall-L. Both models had variance-covariance matrices that were positive definite. However, overall model performance was optimized with the removal of Fall-L (Fall-L removed χ^2 = 21.94 vs. Fall-R removed χ^2 = 19.85). Subsequently, the Fall-L item was removed from further analyses. The removal of the Fall-L item was not viewed as detrimental as Fall-L appeared to be providing redundant co/variance which could be sufficiently provided by Fall-R. Further, Fall-L and Fall-R were the same task performed unilaterally, therefore, the reactive postural response system was represented in the 7-item Brief-BESTest, albeit, in a more succinct manner.

To verify the factor structure (i.e., construct validity) of the Brief-BESTest items it was hypothesized that the Brief-BESTest would be composed of a single balance factor (i.e., global balance), however, a competing two-factor model (i.e., dynamic and static balance; Bass, 1939) was also run. Global fit indices for both models can be found in Table 3.4. Both models performed fairly well, however, the two-factor model was slightly superior (see Figure 3.3). This we reinforced by a scaled-χ^2 test (Satorra, 2000) which showed a significant difference between the two models (p = .001) favoring the two-factor model. The χ^2 value for the two-factor model was low enough to retain the null hypothesis highlighting evidence of exact fit between the model and the model reproduced by the data (p = .10, df = 13). The null hypothesis for the $\chi^2(13)$ test of model fit (19.85) was retained, the CFI (.99) and the TLI (.98) were above 0.95, and the SRMR (.07) was below .08. However, the RMSEA (.07) was above 0.06. In recent years, the RMSEA has been touted as "one of the most informative fit indices" (Diamantopoulos & Siguaw, 2000, p. 85), however, an RMSEA of .07 has been suggested as a strict upper limit (Steiger, 2007). Given all of the global fit outcomes, it was concluded that the two-factor model was satisfactory.

Regarding local fit, multiple indices were examined (see Table 3.5). Standard errors were somewhat acceptable as three standard error values were > .10, however, none were > .15 (i.e., Fall-R, Reach, Foam). All standardized parameter estimates performed uniformly within each factor and were > .50 while all R^2 values for each item were > .10. Based on the z- and p-values, all parameters were found to be significant in the model. Regarding residuals, a covariance-based unstandardized residual polychoric correlation matrix was produced. The matrix was unstandardized because a standardized residual matrix could not be intuitively calculated using WLSMV estimation. Four of the residual-based correlations were > .10 (i.e., UpGo/Reach, Fall-R/Single-L, Reach/Foam, Single-R/Foam) suggesting four of the 28 inter-item relationships were not optimally captured by the model (i.e., increased error correlations at the latent level). All other measures of local fit were satisfactory within the two-factor model. As such, the two-factor model was determined to be justifiable in lieu of the standard error and residual correlation caveats.

Concerning modification indices for the two-factor model, only one path was statistically significant (i.e., a path from the dynamic balance factor to the Single-L item) which would have decreased the χ^2 test of model fit by 5.74. However, decreasing the χ^2 statistic for the two-factor model was not needed as the null hypothesis ($p > .05$) was retained. Further, the CFA analyses were not exploratory in nature as the addition of modification indices path(s) could have caused over-fitting/reduced the generalizability of the model. Thus, a congeneric (i.e., simple structure) and parsimonious model was maintained.

Finally, using additional balance assessments, the convergent validity of the Brief-BESTest was investigated. For the composite AR-YBT classification (i.e., maximum normalized left reach + maximum normalized right reach), the quantile cutoffs were < 24.6, < 95.2, < 119.2, and ≥ 119.2. Using Fisher's transformation, the average bias-corrected inter-item correlation was .37 suggesting a moderate relationship between the balance assessments (Clark & Watson, 1995). Descriptive results for the zero-order Spearman correlations using total scores for all five balance assessments can be found in Table 3.6. Brief-BESTest total score zero-order Spearman correlations ranged from -.36 (i.e., Brief-BESTest/Sway) to .67 (Brief-BESTest/AR-YBT) and all were statistically significant ($p < .001$). Given the full correlation matrix (see Table 3.7), two out of ten associations were not statistically significant (i.e., Sway/AR-YBT, Sway/Turn). However, this study focused upon the Brief-BESTest results, therefore, these results were not extensively discussed hereafter.

Discussion

The purpose of this study was to examine the construct and convergent validity of Brief-BESTest scores in youth with VIs. While the Brief-BESTest examined six operationalized balance systems (Padgett et al., 2012), it was reasonable to theoretically situate the Brief-BESTest systems/items within the dynamic-static balance paradigm. As such, contrary to the original hypothesis of this study, the psychometric properties of the seven-item Brief-BESTest were found to perform best in youth with VIs when two latent factors were operationalized within the CFA framework (i.e., dynamic and static balance). Thus, from a theoretical perspective, researchers and practitioners should consider aligning/interpreting individual item scores from the Brief-BESTest within a static-dynamic framework in youth with VIs (i.e., two-dimensional). Given the totality of the evidence, the construct validity of Brief-BESTest scores in youth with VIs was deemed acceptable.

Further, it is critical to note that the covariance between the static and dynamic latent factors was significant to the model (loading = .85) suggesting a strong relationship between the two latent factors. Such a finding suggests that (when using the Brief-BESTest in youth with VIs) static and dynamic balance factors are highly related at the latent level, a finding that contradicts previous correlational static-dynamic findings (Drowatzky & Zuccato, 1967; Hempel & Fleishman, 1955; Tsigilis et al., 2001).

Both the Fall-R and the Fall-L items assessed the reactive postural response balance system, albeit bilaterally. However, the Fall-L item was dropped from the CFA analyses due to minor multicollinearity concerns with the Fall-R item. The Fall-L and Fall-R redundancy occurred as the scores for the Fall-L and Fall-R items were similar

(Fall-L: M = 1.91, SD = .72; Fall-R: M = 1.87, SD = .76) suggesting that there was limited variability between the right and left sides (on average) in youth with VIs. Therefore, it is suggested that the Brief-BESTest could be used as a seven-item (i.e.., exclude Fall-L) and/or an eight-item (i.e., include Fall-L) balance battery in youth with VIs. By removing the Fall-L item, assessors could lose variability among certain individuals when calculating a total score. Further, by keeping the Fall-L item, multicollinearity could occur. Therefore, if the eight-item Brief-BESTest is utilized, assessors should proactively investigate for multicollinearity when applicable. Yet, for BESTest-related balance batteries, it has been suggested that only the lowest score of a bilaterally scored item should be used (King & Horak, 2013). Thus, future validity analyses should examine using the lowest score of the Fall-R/Fall-L and Single-R/Single-L items which would provide equal representation of the six operationalized Brief-BESTest balance systems when calculated a cumulative score (i.e., *six* items and six systems vs. *eight* items and six systems).

Last, the convergent validity of the Brief-BESTest was examined using total scores from various balance assessments (i.e., AR-YBT, 360-degree turn, sway, ABC Scale). Overall, results suggested that the Brief-BESTest had strong-to-moderate monotonic associations with the utilized dynamic (i.e., AR-YBT, 360-degree turn), static (i.e., quiet stance postural sway), and psychological (i.e., ABC Scale) balance assessments in youth with VIs (ρ = .67 to -.36, p < .001). Given the magnitude and significance level of the correlations with the Brief-BESTest, these outcomes contradict past static-dynamic balance associational investigations (Burton & Davis, 1992; Drowatzky & Zuccato, 1967; Tsigilis et al. 2001) suggesting that the Brief-BESTest measured balance performance in a holistic/utilitarian manner in youth with VIs. These results are supported by Huang and Pang (2017) who recently found strong convergent validity for Brief-BESTest total scores in individuals with chronic stroke. In conclusion, total Brief-BESTest scores (i.e., the sum of all the Brief-BESTest items) in youth with VIs were determined to have an acceptable level of convergent validity.

Conclusion

Validity is a continuum rather than a binary categorization (i.e., yes/no). Thus, given the results of the current analyses, it was concluded that Brief-BESTest scores in youth with VIs presented with sufficient degrees of construct and convergent validity and therefore can be used to assess multidimensional balance in youth with VIs. It is important to note that certain items performed suboptimally compared to other Brief-BESTest items (i.e., Foam, ceiling effect) or where somewhat redundant at times (i.e., Fall-R/Fall-L, mildly multicollinear). However, all of the Brief-BESTest items were viewed as useful and enabled a comprehensive multidimensional investigation of balance in youth with VIs.

Limitations

Limitations of this study include the use of a convenience sample and an acceptable but smaller sample size then typically suggested for EFA and CFA analyses. Also, the B4 categorization was the least represented vision level within the sample (8%) and a majority of the sample was White (70%). Last, the Brief-BESTest only contained one to two items per system (i.e., factor) making it unfeasible to examine the factorability of all six systems (i.e., hierarchical CFA) which would have enabled an in-depth investigation of the systems framework for postural control (Sibley, Beauchamp, Van Ooteghem, Straus, & Jaglal, 2015) in youth with VIs.

Implications for Practice

Based on the results of this study, the Brief-BESTest (which is practitioner-friendly, inexpensive, and quick) should be viewed as a viable balance assessment in youth with VIs. In youth with VIs, the Brief-BESTest can be used to assess specific balance profiles (i.e., six operationalized systems) which could be used to inform targeted learning/therapeutic outcomes or goals (e.g., Individualized Education Program). Both total and individual Brief-BESTest scores in youth with VIs could be used in correlational (e.g., physical activity levels) and experimental study designs.

Table 3.1

Brief-BESTest Descriptive Statistics for Youth with VIs

Assessment	*Mean*	*SD*	*Median*	*Skew*	*Kurtosis*	*SE*
UpGo	2.77	.44	3.00	-1.61	1.45	.04
Fall-R	1.87	.76	2.00	-1.02	1.17	.08
Fall -L	1.91	.72	2.00	-1.29	2.13	.07
Foam	2.83	.57	3.00	-3.60	12.80	.06
Hip	1.44	.92	1.00	-.04	-.89	.09
Reach	2.01	.90	2.00	-.83	.07	.09
Single-R	1.28	1.02	1.00	.44	-.93	.10
Single-L	1.18	.99	1.00	.55	-.73	.10
Total	15.29	4.52	16.00	-.77	.79	.45

Table 3.2

Zero-order Spearman Inter-item Correlations for the Brief-BESTest in Youth with VIs

Item	UpGo	Fall-R	Fall-L	Foam	Hip	Reach	Single-R
Fall-R	.38*** (.20, .54) *Moderate*						
Fall-L	.44*** (.27, .59) *Strong*	.73*** (.62, .81) *Very Strong*					
Foam	.18 (-.02, .36) *Negligible*	.23* (.04, .41) *Weak*	.28** (.09, .45) *Weak*				
Hip	.35*** (.17, .51) *Moderate*	.34*** (.15, .50) *Moderate*	.33*** (.15, .50) *Moderate*	.22* (.03, .40) *Weak*			
Reach	.34*** (.15, .50) *Moderate*	.52*** (.37, .65) *Strong*	.40*** (.22, .55) *Strong*	.34*** (.16, .50) *Moderate*	.41*** (.24, .56) *Strong*		
Single-R	.42*** (.25, .57) *Strong*	.40*** (.22, .55) *Strong*	.45*** (.28, .59) *Strong*	.25* (.06, .42) *Weak*	.41*** (.23, .56) *Strong*	.55*** (.40, .67) *Strong*	
Single-L	.35*** (.17, .51) *Moderate*	.34*** (.15, .50) *Moderate*	.42*** (.24, .57) *Strong*	.32*** (.14, .49) *Moderate*	.53*** (.37, .66) *Strong*	.54*** (.39, .67) *Strong*	.73*** (.62, .81) *Very Strong*

Note. Parenthesis are 95% CIs. ρ interpretations are in italics. * = ≤ .05, ** = ≤ .01, *** = ≤ .001

Table 3.3

One-factor Minimum Residual/Oblimin EFA Loadings for the Brief-BESTest in Youth with VIs

Item	Item #	*Loading*	h^2	u^2
Fall-L	3	.75	.56	.44
Fall-R	2	.74	.54	.46
Reach	4	.72	.51	.49
Single-R	6	.68	.46	.54
Single-L	7	.67	.44	.56
UpGo	1	.61	.38	.62
Hip	5	.57	.33	.67
Foam	8	.48	.23	.77

Note. Variables sorted by standardized loading in descending order.

Table 3.4

WLSMV CFA Global Fit Indices for the (7-Item) Brief-BESTest in Youth with VIs

Model	Factors	Estimator	χ^2	*df*	χ^2/df	*CFI*	*TLI*	*SRMR*	*RMSEA*
1	1	DWLS	16.54	14	1.18	.998	.996	.075	.04 (.00, .11)
		Robust	**28.90***	**14**	**2.06**	**.98**	**.97**	**.075**	**0.10 (.05, .16)**
2	2	DWLS	11.17	13	.86	1.00	1.00	.068	.00 (.00, .09)
		Robust	**19.85**	**13**	**1.53**	**.99**	**.98**	**.068**	**.07 (.00, .13)**

Note. Data were specified as ‘ordered’ (i.e., ordinal). Robust values bolded for emphasis. RMSEA CIs set at 90%. * = ≤ .05

Table 3.5

WLSMV CFA Local Fit Indices for the (7-Item) Brief-BESTest in Youth with VIs

Item/Factor	Path	*Estimate*	*SE*	*z*	*Standardized*	R^2
UpGo	Dynamic	1.00			.79	.63
Fall-R	"	.93	.14	6.47***	.74	.54
Reach	"	1.09	.15	7.44***	.86	.75
Single-R	Static	1.00			.86	.74
Single-L	"	1.05	.08	13.30***	.90	.81
Foam	"	.84	.13	6.56***	.72	.52
Hip	"	.76	.08	9.36***	.66	.44
Dynamic/ Static	Covariance	.85	.07	7.92***	.85	--

Note. *** = ≤ .001

Table 3.6

Descriptive Statistics for Five Balance Assessments (Total Scores) in Youth with VIs

Assessment	*Mean*	*SD*	*Median*	*Skew*	*Kurtosis*	*SE*
Brief-BESTest	15.29	4.52	16.00	-.77	.79	.45
AR-YBT	2.49	1.13	2.00	.02	-1.40	.11
Turn	355.49	104.25	362.65	-.05	.18	10.37
Sway	.11	.18	.06	5.32	36.69	.02
ABC Scale	82.78	11.30	85.00	-.85	.83	1.12

Table 3.7

Zero-order Spearman Correlations for Five Balance Assessments (Total Scores) in Youth with VIs

Item	Brief-BESTest	AR-YBT	Turn	Sway
AR-YBT	.67*** (.54, .76) *Strong*			
Turn	.48*** (.32, .62) *Strong*	.41*** (.23-.56) *Strong*		
Sway	-.36*** (-.52, -.17) *Moderate*	-.13 (-.31, .07) *Negligible*	-.08 (-.27, .12) *Negligible*	
ABC Scale	.46*** (.30, .60) *Strong*	.44*** (.27, .59) *Strong*	.27** (.08, .44) *Weak*	-.21* (-.39, -.02) *Weak*

Note. Parenthesis are 95% CIs. ρ interpretations are in italics. * = ≤ .05, ** = ≤ .01, *** = ≤ .001

Figure 3.1 Side-by-side original (left) and modified (right) YBT stance platform.
Note. On the modified stance platform, note the cylindrical shape (i.e., rolled tape) taped on top of the stance line used to provide tactile/haptic feedback.

Figure 3.2 Side-by-side original (left) and modified (right) YBT reach platform.
Note. On the modified reach platform, note the multi-colored taped on the front side of the platform used to provide visual contrast.

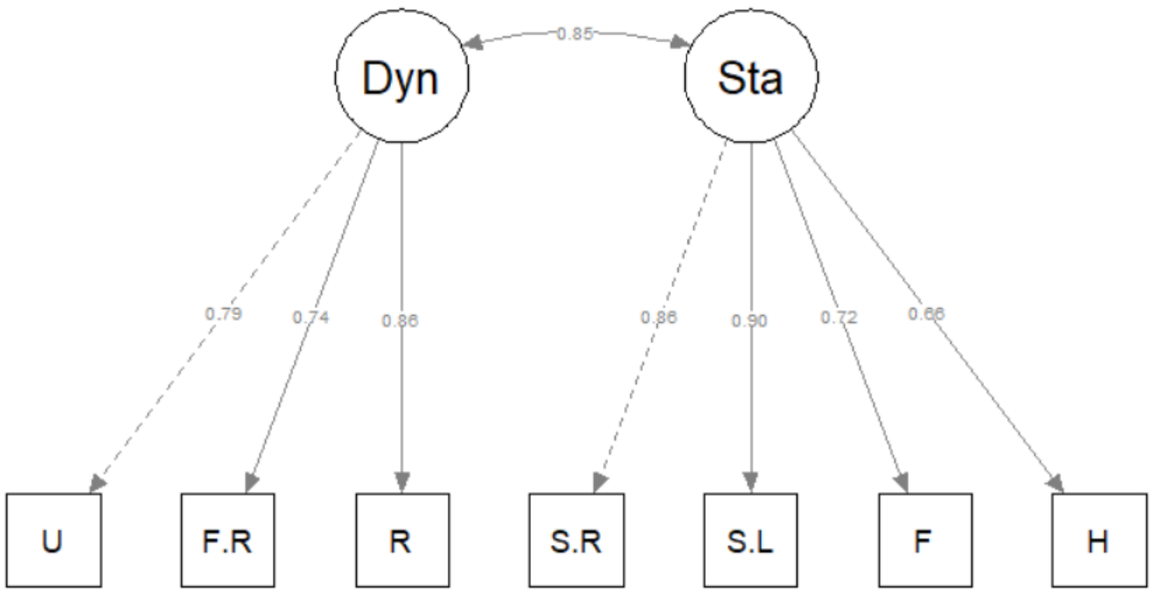

Figure 3.3 Two-factor WLSMV CFA model selected for the (7-item) Brief-BESTest in youth with VIs.

Note. Dyn = Dynamic; Sta = Static; U = UpGo; F.R = Fall-R; R = Reach; S.R = Single-R; S.L = Single-L; F = Foam; H = Hip

CHAPTER 4: STUDY 2

A COMPARISON OF MULTIDIMENSIONAL BALANCE IN YOUTH WITH AND WITHOUT VISUAL IMPAIRMENTS

Introduction

When youth with and without VIs have been compared, most studies have concluded that youth with VIs have some form of impaired balance performance (Bouchard & Tetreault, 2000; Engel-Yeger, 2008; Gipsman, 1981; Grbovic & Jorgic, 2017; Häkkinen et al., 2006; Houwen et al., 2008; Leonard, 1969; Navarro et al., 2004; Pereira, 1990; Ribadi et al., 1987; Uysal & Düger, 2011; Wyver & Livesey, 2003). However, comparisons to peers without VIs have been inconsistent (Case et al., 1973; Johnson-Kraemer et al., 1992), lacked empirical rigor (Houwen et al., 2009b), or have used unidimensional or oversimplified balance assessments (Horak, 2006).

Balance is an act, not a state (Reed, 1989) and can be defined as "a multidimensional concept, referring to the ability of a person not to fall" (Pollock et al., 2000, p. 405). Further, balance is a complex and contingent skill which has led researchers to question the nature of balance and balance assessment (Burton & Davis, 1992; Horak, 2006; Skaggs & Hopper, 1996; Reed, 1989; Overlock & Jun, 2004). In recent years, researchers have introduced a 'systems-based' framework which has led to the creation of multidimensional balance assessments (Horak et al., 2009; Sibley et al., 2015).

One such example is the Brief-Balance Evaluation Systems Test (Brief-BESTest; Padgett et al., 2012). Recently, Brief-BESTest scores from youth with VIs were found to have internal consistency reliability as well as construct and convergent allowing for the novel investigation of balance system performance in youth with and without VIs validity (Pennell et al., in prep). Thus, the purpose of this study was to compare total and individual item Brief-BESTest scores between youth with and without VIs. It was hypothesized that youth with VIs would score significantly lower ($p < .05$) than youth without VIs on the individual item and total scores from the Brief-BESTest.

Methods

Participants and Setting

Using convenience sampling, youth with and without visual impairments (N = 287) were recruited from Camp Abilities Brockport (NY) Saratoga Springs (NY), Starke (FL), Governor Morehead School for the Blind (NC), and several schools within a K-12 school district (SC). Descriptive information for the sample was as follows: M_{age} = 13.80 years ± 2.32, $M_{maturityoffset}$ = 1.15 ± 1.89, M_{height} = 1.59 meters (m) ± .13, M_{weight} = 59.60 kilograms (kg) ± 19.76, M_{BMI} = 23.24 kg/m^2 ± 5.98, and $M_{BMI\%}$ = 65.52 ± 28.13. Fifty-nine percent of the participants were boys (n = 170). Regarding race, 18% were Black (n = 51), 19% were Other (n = 56), and 63% were White (n = 180). Concerning visual classification, 55% did not have a visual impairment (n = 158) while 45% (n = 129) had a visual impairment (B4 = 22, B3 = 37, B2 = 32, B1 = 38). Thirty-six percent of youth with visual impairments had a comorbidity (n = 46).

Instrumentation

Demographics. A self-report demographic and visual information questionnaire was completed by the participant or by a parent/guardian while the participant was present.

Anthropometrics. Standing height as well as weight were assessed while barefoot. Standing height and weight were used to determine BMI percentiles (United States Department of Health and Human Services, 2010). Predicted maturity offset (i.e., years before or after peak height velocity [PHV]) was estimated with the Moore-1 or the Moore alternative sex-specific equations (Moore et al., 2015). Subsequently, an estimate of age at PHV was calculated (i.e., predicted maturity offset - age; Mirwald et al., 2002).

Brief-BESTest. The Brief-BESTest had not been investigated in youth with (or without) VIs previously, therefore, a comparison group of youth without VIs was required in order to interpret Brief-BESTest scores. Further, the Brief-BESTest had increased utility compared to past balance assessments as it enabled the specific examination of multiple balance performance constraints/mechanisms as posited by the systems framework for postural control (Horak, 2006; Horak et al., 2009; Sibley, Beauchamp, Van Ooteghem, Straus, & Jaglal, 2015).

The Brief-BESTest was used to assess six balance systems (i.e., eight items). The Brief-BESTest has been found to be reliable and valid in separate populations (Jácome et al., 2016; O'Hoski et al., 2015; Padgett et al., 2012). The six systems and the eight respective items are as follows: (a) biomechanical constraints—hip/trunk lateral strength (Hip), (b) stability limits—functional reach forward (Reach), (c) transitions—standing on one leg on each side (Single-R; Single-L) (d) reactive—lateral compensatory stepping on each side (Fall-R; Fall-L), (e) sensory orientation—standing with eyes closed on foam (Foam), and (f) stability in gait—timed “up and go” (UpGo). Participants were digitally recorded performing the Brief-BESTest and retroactively scored using an ordinal scale (i.e., 0-3) for each item. Each of the eight test items were combined to create a composite score between 0 and 24. Higher scores represented better balance performance. Total test time ranged around 10 minutes per participant.

Procedures

Internal Review Board approval was granted by the University of South Carolina for this study. Research sites which agreed to participate in this study included Camp Abilities Brockport (NY), Saratoga (NY), Starke (FL), Governor Morehead School for the Blind (NC), and several schools within a K-12 school district (SC). At each site for youth with visual impairments (VI), participants were recruited in a face-to-face format where signed parental and/or participant consent and demographic questionnaires were completed. At the Governor Morehead School, data collection occurred during one-hour timeslots in the evening (i.e., after school). At Camp Abilities, data collection occurred during one-hour timeslots in the morning or evening. All data were collected in 2017 and 2018.

At each site for youth without VIs (i.e., the K-12 school district in SC) participants were recruited at an intermediate and middle school by sending home consent forms which were returned to the site-specific physical education teacher(s). One high school site also participated, however, only passive consent was required at the high school. At the K-12 schools, data collection occurred during the participants regularly schedules physical education course (i.e., morning or afternoon).

During data collection, participants were anthropometrically assessed and then completed the Brief-BESTest while barefoot. The Brief-BESTest was digitally recorded and retroactively coded.

Analysis

Data screening/preparation. All analyses were conducted using R statistical software (R Core Team, 2013). Prior to statistical analyses the aggregated data was assessed for missingness. Percent, patterns, and mechanisms of missingness were found to be satisfactory for imputation (Bennett, 2001; Dong & Peng, 2013; Kang, 2013; Rubin, 1976). Missing cells were imputed using the *missForest* package (Stekhoven & Bühlmann, 2012). Estimated error levels for the imputation were satisfactory (Oba et al., 2003; Stekhoven & Bühlmann, 2012). Following the completion of the imputation, the dataset was screened for normality and outliers to inform subsequent statistical analyses.

Total and item Brief-BESTest scores were assessed for univariate normality using the Shapiro-Wilk test. All variables of interest were found to be non-normal ($p < .001$). Royston's multivariate normality test confirmed a lack of multivariate normality for the individual Brief-BESTest items ($H = 753.04$, $p < .001$). As such, homogeneity of variance was assessed using modified Flinger-Killeen tests which are robust to non-normal data. Issues of heteroscedasticity of variance for all variables of interest were found ($p < .05$). Further, homogeneity of the variance-covariance matrix was not confirmed using Box's M test ($p < .001$). Outliers were determined using the 'fence' method (±1.5 * interquartile range; interquartile range = type 7). Five (1.74%) participants were identified as outliers due to their total score. All outliers were deemed relevant to the sample, therefore, none of the outliers were removed from the dataset.

Last, the absence of multicollinearity was confirmed (*det* = .05 where <.00001 = multicollinearity issues, Field, 2000; all variance inflation factors were < 4, Vatcheva et al., 2016).

Descriptives. Measures of central tendency and spread were calculated for all applicable variables.

Difference tests. A one-way analysis of variance (ANOVA) was used to assess for a difference between youth with and without VIs for total Brief-BESTest scores. Next, a one-way multivariate analysis of variance (MANOVA) was used to assess for differences for each of the Brief-BESTest items: UpGo, Fall-R, Fall-L, Reach, Hip, Single-R, Single-L, and Foam. Due to the aforementioned normality and homoscedasticity concerns, α was set to .01 (Tabachnick & Fidell, 2019).Omega-squared (ω^2) was used to determine effect sizes (Yigit & Mendes, 2018). Omega-squared is fairly analogous to eta-squared (η^2; Sechrest & Yeaton, 1982), therefore, common eta-squared cutoffs were used where values ≥ .14, .06, and .01, equated to large, medium, and small effects (Stevens, 2002) as previously defined within the social/behavioral sciences (Cohen, 1998; Ialongo, 2016). Further Pillai's trace (*V*) was used for the MANOVA (Olson, 1974) with the same eta-squared effect size cutoffs as eta-squared is equivalent to Pillai's trace (Norman & Streiner, 2014). Subsequent Games-Howell *post hoc* analyses were run.

Confounding variables in youth with VIs. It is reasonable to assume that characteristics such as biological sex, age-band, vision level, et cetera could have a confounding influence on balance performance in youth with VIs. Within the current study, age-band was particularly important to investigate given the wide range of ages within the sample (i.e., eight to 20 years). As such, data for youth with VIs were subsetted from the master data set (n = 129). Differences by vision level (i.e., B1, B2, B3, B4) were examined. Multiple screening analyses (i.e., side-by-side boxplots, point-biserial or zero-order Spearman correlations, Wilcoxon-Mann-Whitney or Kruskal Wallis) were run to identify potential confounding variables for Brief-BESTest total scores by vision level. Potential covariates of interest that were examined included: biological sex (i.e., boy, girl), age-band (i.e., 8-11, 12-14, ≥ 15), BMI% categorization (i.e., underweight, normal, overweight, obese), and the presence of a comorbidity (i.e., yes, no). After addressing the necessary assumptions, a one-way analysis of covariance (ANCOVA) was run with α set to .05.

Results

Total and item score descriptive results for the Brief-BESTest in youth with and without VIs can be found in Table 4.1. Total Brief-BESTest scores between youth with and without VIs were statistically significant (F = 225.13, p < .001, ω^2 = .44, ω^2 95% CI = .36, .51, Δ = -5.53, p < .001). Concerning the eight individual Brief-BESTest items, the one-way MANOVA analysis was statistically significant (F = 43.07, p < .001, V = .55). Games-Howell *post hoc* analyses highlighted significant differences between all Brief-BESTest tasks except for the Foam task (see Table 4.2).

Using Wilcoxon-Mann-Whitney or Kruskal Wallis analyses for the subsetted sample of youth with VIs, significant differences were found by comorbidity categorization and level of vision. Using point-biserial or Spearman correlations, again, only comorbidity categorization and level of vision were significant (see Table 4.3). Based on these results, age-band, biological sex, and BMI% categorization were eliminated as potential confounding variables for Brief-BESTest total scores in youth with VIs.

Brief-BESTest total scores in youth with VIs were found to lack normality ($p < .001$), however, using the Brown-Forsythe Levene test, Brief-BESTest scores for youth with VIs were found to have equal variance by vision level ($p = .62$). Five (3.88%) participants were identified as outliers based on their total Brief-BESTest scores. All outliers were deemed relevant to the sample, therefore, none of the outliers were removed from the dataset. Finally, using total Brief-BESTest scores, an ANCOVA was run using vision level as the primary factor with the presence of a comorbidity as the covariate. Both vision level ($F = 3.60$, $p = .016$, $\omega^2 = .04$) and comorbidity ($F = 51.21$, $p < .001$, $\omega^2 = .27$) were significant to the model.

Discussion

The purpose of this study was to compare total and item Brief-BESTest scores between youth with and without VIs. The findings of the current study suggested that youth with VIs had significantly lower Brief-BESTest total scores than youth without VIs. Further, seven out of eight Brief-BESTest item scores (i.e., five out of six balance systems) were significantly lower in youth with VIs. This discussion will address each result as situated within its respective postural control system with an emphasis on effect size (ω^2) results.

Transitions—anticipatory postural adjustment (Single-R; Single-L). The Single-R/Single-L items assessed postural compensations following an anticipated postural transition/destabilization (Horak et al., 2009). Importantly, Single-R ($\omega^2 = .46$, 95% CI = .38, .53) and Single-L ($\omega^2 = .50$, 95% CI = .42, .56) were the most impaired balance system in youth with VIs based on effect sizes. Using similar assessments, Häkkinen and Navarro and colleagues (2006, 2004) previously found that youth with VIs had impaired unipedal stance times when compared to youth without VIs. In fact, others have concluded that vision may play a more substantial role in static (as opposed to dynamic) balance tasks in youth with VIs (Bouchard 1996; Houwen et al., 2008). Within the current sample, a potential mechanism for these findings could be missing/conflicting visual information (as vision assists with specifying body position; Hatzitaki et al., 2002; Riach & Hayes, 1987), fear of falling, and/or limited experience, development, and/or control of the ankle complex, neuromuscular co-contraction, or core (i.e., lumbopelvic-hip complex) stability. Importantly, Single-R and Single-L were purported to assess anticipatory postural adjustments (i.e., activation *prior* to perturbation), however, compensatory postural adjustments initiated by sensory feedback signals *after* a perturbation were also at play (Alexandrov et al., 2005; Park et al., 2004; Santos, Kanekar, & Aruin, 2010). Although the contribution of anticipatory/compensatory postural adjustments cannot be elucidated within the current study, one could speculate that impaired unipedal anticipatory and/or compensatory postural adjustment strategies could impede or constrain the performance of other unipedal static or dynamic (e.g., hopping) tasks in youth with VIs.

Biomechanical constraints (Hip). The Hip item measured functional hip strength/postural alignment for standing (Horak et al., 2009) and was the second most impaired balance system in youth with VIs based on effect size (ω^2 = .26, 95% CI = .18, .35). Overall, it is suggested that youth with VIs may have difficulties maintaining a vertical trunk while abducting their hip when compared to youth without VIs. Potential mechanism for this issue could be impaired hip mobility or strength, neuromuscular co-contraction, and/or core stability. These results provide additional support of the Single-R and Single-L findings suggesting that future interventions may want to emphasize the development of static (and likely dynamic) unipedal balance in youth with VIs.

Stability limits (Reach). The Reach item measured how far participants were willing to shift their center of mass over their base of support (Horak et al., 2009) and was the third most impaired balance system in youth with VIs based on effect size (ω^2 = .20, 95% CI = .13, .28). It could be suggested that youth with VIs may have constraints which limit them from shifting their center of mass into precarious positions. This phenomenon could be described as a stability-mobility trade-off (Horvat et al., 2003; Ray, 2004; Ray et al., 2007) whereby youth with VIs are not willing to compromise their typical posture for a more dynamic and unstable postural state (i.e., postural hesitance/cautiousness). Biomechanical (e.g., mobility, strength, size) and/or psychological (e.g., fear; Hauck, Carpenter, & Frank, 2008) mechanisms may have been potential culprits for this outcome.

Stability in gait (UpGo). The UpGo item assessed coordination between locomotor and sensorimotor programs (Horak et al., 2009) and was the fourth most impaired balance system in youth with VIs based on effect size (ω^2 = .16, 95% CI = .09, .24). This finding was not entirely surprising as individuals with VIs have been found to have altered gait strategies compared to those without VIs (Ray et al., 2007; Pogrund & Rosen, 1989; Rosen, 1989; Sleeuwenhoek, Boter, & Vermeer, 1995). Again, this provides evidence that youth with VIs may exhibit compensatory strategies and/or increased cautiousness during postural tasks as previously discovered in adults with VIs

(Horvat et al., 2003; Ray, 2004; Ray, Horvat, Croce, Mason, & Wolf, 2008; Ray et al., 2007).

Reactive postural response (Fall-R; Fall-L). The Fall-R/Fall-L items assessed automatic stepping responses following an external perturbation (Horak et al., 2009). Effect sizes for the Fall-R (ω^2 = .05, 95% CI = .01, .11) and Fall-L (ω^2 = .03, 95% CI = .01, .09) were small but suggested that youth with VIs may have had slightly impaired sensorimotor feedback loops (Jacobs & Horak, 2007) when compared to youth without VIs. In youth without VIs, motor responses speed (i.e., reaction time measures) were found to associate with medio-lateral postural responses during a dynamic balance task (Hatzitaki et al., 2002). Therefore, it is reasonable to hypothesize that youth with VIs may have larger lateral plane automatic postural response latencies and/or utilize a more involved change-in support strategy (e.g., taking multiple steps; Pollock et al., 2000) compared to youth without VIs. However, further examination of these relationship is needed. Additional neuromuscular mechanisms such as strength and power could also be at play (Ray, 2004) which could lead to decreased response capacities to perturbations (e.g., increased movement reaction times) in youth with VIs. It is important to note that previous research examining associations between balance, strength, and power have conflicted (Forte, Boreham, De Vito, Ditroilo, & Pesce, 2014; Muehlbauer, Gollhofer, Granacher, 2015). Yet, strength and power training have been shown to improve balance performance in various populations (Filipa, Byrnes, Paterno, Myer, & Hewett, 2010; Lee & Park, 2013; Orr et al., 2006) providing evidence that a certain threshold of efferent neuromuscular interdependence likely exists between balance, strength, and power performance.

Sensory orientation (Foam). The Foam item measured sensory integration Horak et al., 2009). The Foam item was the only Brief-BESTest task that was not statistically significant as highlighted be the very small effect size ($\omega^2 = .01$, 95% CI = .00, .05). This outcome highlighted that both youth with and without VIs were able to appropriately re-weight their visual, proprioceptive, and vestibular dependencies (Horak, 2006) signifying that sensory integration may not be constraining balance performance in youth with VIs. This result suggested that having a VI (in of itself) may not be a primary sensory modality of concern for balance performance in youth with VIs. However, it is important to note that the Foam item was a controlled static balance task, therefore, conclusions cannot be made at this time concerning sensory strategies used in more dynamic/functional tasks when comparing youth with and without VIs (e.g., traversing a dimly lit outdoor courtyard).

Conclusion

The results of this study align with previous studies suggesting that balance performance is impaired in youth with VIs when compared to youth without VIs. Within the current sample, youth with VIs were found to perform worse in both dynamic (i.e., UpGo, Fall-R, Fall-L, Reach) and static (Single-R, Single-L, Hip) balance tasks equating to differences in five out of the six proposed balance systems (Horak et al., 2009). However, the prognosis of these differences should not be viewed as unsurmountable as having a VI may not be the primary mechanism of concern regarding balance deficits (Horvat et al., 2003). Indeed, Nakata and Yabe have posited that having a VI in youth "may affect a volitional act mediated through the motor cortex" (p. 36). Further, as Horvat and colleagues previously concluded, "it appears that [a] lack of vision, although important for efficient movement [i.e., balance], can be compensated for largely by a high level of somatosensory and vestibular function" (2003. p. 700) a conclusion that echos the re-weighting hypothesis elucidated by Peterka (2002).

It has been suggested that during early development, youth with VIs motorically lag behind peers who do not have VIs (Brambring, 2006a; Schneekloth, 1989). Schneekloth (1989) suggested that early motor development discrepancies in youth with VIs were due to (a) motor passivity (i.e., unwillingness to explore), (b) self-manipulation as opposed to environmental-manipulation, and (c) immature play behaviors—all of which were likely influenced by congenital vision loss. However, youth with VIs have been shown to compensate as they age either due to verbal and/or physical guidance (Brambring, 2006a; Sleeuwenhoek et al., 1995). Further, after the age of seven, dominance of the visual system typically decreases for postural tasks (Assaiante &, Amblard, 1995; Riach & Hayes, 1987; Shumway-Cook & Woollacott, 1985) allowing another (albeit delayed) window of opportunity for youth with VIs to motorically develop. Such evidence was also noted by de Sousa Santos, Bakke, de Oliveira and Sarinho (2018) who found that youth with VIs began to top out the Pediatric Balance Scale (Franjoine, Gunther, & Taylor 2003) after the age of seven.

Further, previous interventions have successfully improved balance in individuals with VIs (Elsman et al., 2019; Paravlic et al., 2016; Sravani & Metgud, 2014; Suveren-Erdogan, 2018; Suveren-Erdogan, Er, & Suveren, 2018). Thus, it may be that environmental and sociological barriers are primarily responsible for the differences in balance performance identified within the current study (e.g., less motor development affordances/participation, over protection; United States Department of Health and

Human Services, 2018a, Lieberman & Houston-Wilson, 1999; Sugden & Wade, 2013) which could be fostering negative spirals of disengagement and/or impaired neuromuscular, motoric, and health-related trajectories in youth with VIs. Thus, while having a VI could be viewed as disadvantageous for balance performance, having a VI may be more of the *why* than the *how* for these youth.

Importantly, the utility of the Brief-BESTest allowed for the identification of specific and operational postural discrepancies (i.e., mechanisms/systems/constrains) as opposed to more general conclusions. Based on the implications of this study and the potential for youth with VIs to adapt, it is likely that interventions which target functional dynamic/static balance, total body neuromuscular development, and suprapostural tasks and skills (e.g., object control skills, simultaneous cognitive processing) would likely remediate the balance system discrepancies found within the current sample (in absence of certain comorbidities). To this point, it is important that researchers and practitioners acknowledge that the presence of a comorbidity as well as the severity of an individual's VI are significant confounding variables that should be considered when using the Brief-BESTest with youth with VIs.

Limitations

One limitation of this study was the use of a convenience sample. Specifically, all youth with VIs were from New York, Florida, and North Carolina. In contrast, youth without VIs were from South Carolina due to access and feasibility factors. Also, it is possible that task novelness (e.g., Reach) or decreased participant motivation influenced the results of this study.

Implications for Practice

Practitioners should be comfortable acknowledging that youth with VIs tend to have balance performance deficits in multiple systems when compared to youth without VIs. However, a lack of visual information in of itself should not be viewed as an unyielding sensorimotor constraint as balance performance can be improved in youth with VIs. Therefore, screening, assessing, and/or developing balance systems in youth with VIs should be standard practice in educational and therapeutic settings. Based on the current sample, practitioners should be aware that lower vision levels and (especially) the presence of a comorbidity may be impactful confounding variables concerning balance performance and/or interventions in youth with VIs.

Table 4.1

Brief-BESTest Descriptive Statistics for Youth with and without VIs

Assessment	Group	*Mean*	*SD*	*Median*	*Skew*	*Kurtosis*	*SE*
UpGo	VI	2.73	.46	3	-1.25	.15	.04
	WO	3.00	.00	3	.00	.00	.00
Fall-R	VI	1.88	.72	2	-.92	1.22	.06
	WO	2.15	.41	2	.50	4.85	.03
Fall-L	VI	1.89	.68	2	-1.22	2.30	.06
	WO	2.09	.35	2	.47	9.49	.03
Reach	VI	1.92	.86	2	-.72	.05	.08
	WO	2.62	.50	3	-.64	-1.22	.04
Hip	VI	1.36	.95	2	-.18	-1.11	.08
	WO	2.34	.65	2	-.87	1.33	.05
Single-R	VI	1.21	1.03	1	.52	-.86	.09
	WO	2.71	.56	3	-1.75	2.06	.04
Single-L	VI	1.09	.94	1	.60	-.49	.08
	WO	2.63	.59	3	-1.32	.69	.05
Foam	VI	2.86	.51	3	-4.03	16.61	.05
	WO	2.95	.32	3	-5.99	34.05	.03
Total	VI	14.95	4.21	15	-.60	.83	.37
	WO	20.49	1.77	21	-.98	1.57	.14

Note. VI = youth with VIs; WO = youth without VIs.

Table 4.2

Games-Howell Post Hoc and Effect Size Results for each Brief-BESTest Item in Youth with and without VIs

	UpGo	Fall-R	Fall-L	Reach	Hip	Single-R	Single-L	Foam
Δ	-.27*** (-.35, -.19)	-.27*** (-.41, -.13)	-.20** (-.33, -.07)	-.70*** (-.87, -.53)	-.97*** (-1.17, -.78)	-1.50*** (-1.70, -1.30)	-1.53*** (-1.72, -1.35)	-.09 (-.19, .01)
ω^2	.16 (.09, .24) *Large*	.05 (.01, .11) *Small*	.03 (.01, .09) *Small*	.20 (.13, .28) *Large*	.26 (.18, .35) *Large*	.46 (.38, .53) *Large*	.50 (.42, .56) *Large*	.01 (.00, .05) *Small*

Note. * = ≤ .05, ** = ≤ .01, *** = ≤ .001

Table 4.3

Screening of Potential Confounding Variables in Youth with VIs (n=129)

Variable	Δ Test	Statistic	Corr. Test	Correlation
Sex	WMW	1806	P-BI	-.12
Comorbidity	"	3168***	"	.55
Age-band	KW	4.28	SP	-.03
BMI%	"	4.29	"	.08
Vision level	"	14.97**	"	.29

Note. WMW = Wilcoxon-Mann-Whitney, KW = Kruskal-Wallis, P-BI = point-biserial, SP = Spearman. * = ≤ .05, ** = ≤ .01, *** = ≤ .001

CHAPTER 5: STUDY 3

ASSOCIATION BETWEEN MULTIDIMENSIONAL BALANCE AND THE LOCOMOTOR SUBSCALE OF THE TGMD-3 IN YOUTH WITH VISUAL IMPAIRMENTS

Introduction

Balance (i.e., stability) has been categorized as a fundamental motor skill (Gallahue et al. 2012), however, the role of balance as a fundamental motor skill has been downplayed and/or under-investigated in the field of motor development (Rudd et al., 2015). For example, there is no balance subscale in the Test of Gross Motor Development (TGMD; Ulrich, 2000; Webster & Ulrich, 2017) which is arguably one of the most popular fundamental motor skill assessment batteries in the United States (and elsewhere).

Due to issues of measurement and/or the pluralism of balance (Burton & Davis, 1992; Overlock & Jun, 2004; Skaggs & Hopper, 1996), linear relationships between balance assessment scores and other balance, locomotor, and object control scores have been described as negligible to weak in magnitude (Drowatzky & Zuccato, 1967; Hempel & Fleishman, 1955; Metgud & Honap, 2018; Tsigilis et al., 2001). Similar interpretations have led some researchers to question the role of balance in movement (Klavina et al., 2017; Singh et al., 2015; Ulrich & Ulrich, 1985; Winstein, Gardner, McNeal, Barto, & Nicholson, 1989). As poignantly concluded by Reed (1989, p. 5), “the phenomena of posture have not fit in well with most accounts of movement.”

However, the conclusion that balance and movement are not associated has been regularly contended (Chew-Bullock et al., 2012; Logan, Robinson, & Getchell, 2011; Loovis & Butterfield, 2000; Mache & Todd, 2016; Wang, Long, & Liu, 2012). Further, balance-based skills have been shown to perform adequately alongside locomotor, object control, and other balance-like skills in various motor skill batteries (Bruininks & Bruininks, 2005; Kiphard & Shilling, 1974; Luz et al., 2016; Rudd et al., 2015; Schulz, Henderson, Sugden, & Barnett, 2011) supporting the stance put forth by Reed (1989, p. 21) who posited that "a key factor in constraining motor variability into functional action is [the] adaptable and flexible nesting of movement and posture."

Youth with VIs are 50% more likely to become obese as they age (Weil et al., 2002) and trend with decreased levels of health-related fitness, physical activity, and locomotor/object control/balance competence (Augestad & Jiang, 2015; Häkkinen et al., 2006; Houwen et al., 2008; Houwen et al., 2009a; Uysal & Düger, 2011). Importantly, balance is a lifespan motor skill (Assaiante & Amblard, 1995; Haddad, Rietdyk, Claxton, & Huber, 2013) which underpins a vast majority of human movements (Burton & Davis, 1992; Stoffregen, 2016). Therefore, multidimensional balance skills (Horak, 2006) could be influencing/constraining the health- and movement-based outcomes plaguing youth with VIs (Newell, 1986; Riccio & Stoffregen, 1988).

To the authors' knowledge, only one study has explicitly examined associations between balance and fundamental motor skills in youth with VIs (Metgud & Honap, 2018). Using the kicking and jumping skills from the Adapted Physical Education Assessment Scale (APEAS; Seaman, 1982), the balance error scoring system (BESS; Riemann, Guskiewicz, & Shields, 1999), and the stork balance stand test, Metgud and

Honap (2018) found statistically significant correlations when combining youth with partial and complete blindness ($p < .001$; BESS: $r_{kick} = -.42$, $r_{jump} = -.33$; stork: $r_{kick} = .45$, $r_{jump} = .42$). Interestingly, the authors interpreted the magnitude of the significantly significant associations as weak and concluded that there was "no correlation of static balance with fundamental motor skills in children with visual impairments" (Metgud & Honap, 2018, p. 69). However, caution is warranted regarding this generalization as the correlations were statistically significant, the magnitude of the correlations could be interpreted as strong to moderate (Cohen, 1988; Dancey & Reidy, 2004; Evans, 1996), and not all fundamental motor skills/balance systems were represented within the study.

Given (a) the controversies surrounding balance (e.g., measurement issues, low associations), (b) general uncertainties surrounding the relationship between balance and locomotor/object control skills, and (c) the negative health- and movement trajectories faced by youth with VIs, novel multidimensional balance investigations are warranted. As balance has been posited as an immediate prerequisite for locomotion (Adolph, 2008; Nardini & Cowie, 2012) it is logical to first examine the association between balance and locomotor performance in youth with VIs.

Thus, the purpose of this study was to examine associations between Brief-BESTest scores and the TGMD-3 locomotor subscale scores in youth with VIs. It was hypothesized that all item and total score bivariate correlations between the Brief-BESTest and the TGMD-3 locomotor subscale would be significant ($p < .05$) in youth with VIs.

Methods

Participants and Setting

Using convenience sampling, participants (N = 96) were recruited from Camp Abilities Brockport (NY), Saratoga Springs (NY), and Starke (FL). Descriptive information for the sample was as follows: M_{age} = 12.98 years ± 2.28, $M_{maturityoffset}$ = -.04 ± 1.84 years, M_{height} = 1.55 meters (m) ± .14, M_{weight} = 52.73 kilograms (kg) ± 19.16, M_{BMI} = 21.34 kg/m^2 ± 5.53, and $M_{BMI\%}$ = 62.94 ± 31.43. Concerning visual classification, 22% (n = 21) were B4, 33% (n = 32) were B3, 17% (n = 16) were B2, and 28% (n = 27) were B1. Fifty-four percent of the participants were boys (n = 52) while 28% of the sample (n = 27) had a comorbidity. Regarding race, 15% were Black (n = 14), 16% were Other (n = 15), and 70% were White (n = 67). Seventy-five percent, 20%, and 5% of the sample attended public, schools for the blind, or private schools, respectively.

Instrumentation

Demographics. A self-report demographic and visual information questionnaire was completed by the parent/guardian of each participant while the participant was present.

Anthropometrics. Standing height as well as weight were assessed while barefoot. Standing height and weight were used to determine BMI percentiles (United States Department of Health and Human Services, 2010). Predicted maturity offset (i.e., years before or after peak height velocity [PHV]) was estimated with the Moore-1 or the Moore alternative sex-specific equations (Moore et al., 2015). Subsequently, an estimate of age at PHV was calculated (i.e., predicted maturity offset - age; Mirwald et al., 2002).

Brief-BESTest. The Brief-BESTest was used to assess six balance systems (i.e., eight items). The Brief-BESTest has been found to be reliable and valid in separate populations (Jácome et al., 2016; O'Hoski et al., 2015; Padgett et al., 2012). The six systems and the eight respective items are as follows: (a) biomechanical constraints—hip/trunk lateral strength (Hip), (b) stability limits—functional reach forward (Reach), (c) transitions—standing on one leg on each side (Single-R; Single-L) (d) reactive—lateral compensatory stepping on each side (Fall-R; Fall-L), (e) sensory orientation—standing with eyes closed on foam (Foam), and (f) stability in gait—timed "up and go" (UpGo). Participants were digitally recorded performing the Brief-BESTest and retroactively scored using an ordinal scale (i.e., 0-3) for each item. Each of the eight test items were combined to create a composite score between 0 and 24. Higher scores represented better balance performance. Total test time ranged around 10 minutes per participant.

Test of Gross Motor Development-3. The TGMD-3 (Webster & Ulrich, 2017) is a norm-referenced process-oriented assessment used to evaluate fundamental motor skill competence in youth aged 3 years to 10 years and 11 months. However, it has been stated that the TGMD-3 could be used as a criterion-referenced assessment for those above the age of 10 years and 11 months who do not 'top out' the assessment (Ulrich, 2017). Further, TGMD-3 scores have been shown to be reliable and valid in youth with VIs (Brian et al., 2018).

Youth with VIs were tasked with completing the locomotor subscale of the TGMD-3 (i.e., run, gallop, hop, skip, horizontal jump, slide). For the TGMD-3, two scored trials were completed for each skill. For each trial, a criterion was scored a one if the criterion was performed correctly or a zero if the criterion was not present. Therefore, each skill was worth 6 to 8 points. The total locomotor subscale was worth 48 raw points. Higher scores represented better locomotor performance. Raw TGMD-3 points were used for analyses.

Procedures

Internal Review Board approval was granted by the University of South Carolina for this study. Research sites which agreed to participate in this study included Camp Abilities Brockport (NY), Saratoga (NY), and Starke (FL). At each site, participants were recruited in a face-to-face format where signed parental and/or participant consent and demographic questionnaires were completed. At Camp Abilities, data collection occurred during one-hour timeslots in the morning or evening. During data collection, participants were anthropometrically assessed, completed the Brief-BESTest while barefoot, and then completed the locomotor subscale of the TGMD-3 while shod. The Brief-BESTest and the TGMD-3 locomotor subscale were digitally recorded and retroactively coded. All data were collected in 2018.

Analysis

Data screening/preparation. All analyses were conducted using R statistical software (R Core Team, 2013). Prior to statistical analyses the aggregated data was assessed for missingness. Percent, patterns, and mechanisms of missingness were found to be satisfactory for imputation (Bennett, 2001; Dong & Peng, 2013; Kang, 2013; Rubin, 1976). Missing cells were imputed using the *missForest* package (Stekhoven & Bühlmann, 2012). Estimated error levels for the imputation were satisfactory (Oba et al., 2003; Stekhoven & Bühlmann, 2012). Following the completion of the imputation, the dataset was screened for normality and outliers to inform subsequent statistical analyses.

Individual Brief-BESTest and TGMD-3 locomotor subscale items and total scores were assessed for univariate normality using the Shapiro-Wilk test. All variables of interest were found to be non-normal ($p < .05$). Royston's multivariate normality test confirmed a lack of multivariate normality for the individual Brief-BESTest ($H = 391.25$, $p < .001$) and TGMD-3 locomotor items ($H = 166.02$, $p < .001$). Outliers were determined using the 'fence' method (±1.5 * interquartile range; interquartile range = type 7). Zero outliers were identified for both the Brief-BESTest and the TGMD-3 locomotor subscale.

Descriptives. Measures of central tendency and spread were calculated for all applicable variables.

Associations. Zero-order Spearman correlations (ρ) were used to assess the strength and direction of the monotonic relationship between composite and item scores for the Brief-BESTest and the TGMD-3 locomotor subscale. Absolute value two-tailed bivariate coefficients were classified as very strong ($\rho \geq .70$), strong ($.40 \geq \rho \leq .69$), moderate ($.30 \geq \rho \leq .39$), weak ($.20 \geq \rho \leq .29$), or negligible ($.00 \geq \rho \leq .19$) (Dancey & Reidy, 2004). Multiple first-order partial correlations ($\rho_{yx1.x2}$) were run to identify potentially impactful confounding variables such as biological sex (i.e., boy, girl), age-band (i.e., 8-11, 12-14, ≥ 15), BMI% categorization (i.e., underweight, normal, overweight, obese), and the presence of a comorbidity (i.e., yes, no). If identified as impactful, n^{th}-order partial correlations were performed (e.g., second-order correlations; $\rho_{yx1.x2x3}$) between total scores.

Results

Total and item score descriptive results for the Brief-BESTest and the TGMD-3 locomotor subscale in youth with VIs can be found in Table 5.1. The zero-order Spearman correlation between Brief-BESTest and TGMD-3 locomotor subscale total scores was .60 (p < .001, 95% CI = .46, .72) (see Figure 5.1). Using first-order partial correlations (see Table 5.2), age, sex, race, and BMI% categorization did not influence the correlation between Brief-BESTest and TGMD-3 locomotor subscale total scores ($\rho \approx$ .60). However, first-order partial correlations using the presence of a comorbidity (ρ = .51, p < .001, 95% CI = .35, .64) and vision level (ρ = .52, p < .001, 95% CI = .35, .66) were more impactful. The second-order partial correlation simultaneously controlling for the presence of a comorbidity and vision level was .42 (p < .001, 95% CI = .24, .57). Zero-order correlations between individual Brief-BESTest and TGMD-3 locomotor subscale items ranged from -.09 to .55 (see Table 5.3).

Discussion

The purpose of this study was to investigate associations between Brief-BESTest scores and the TGMD-3 locomotor subscale scores in youth with VIs. Concerning total scores, the zero-order monotonic association was .60 (95% CI = .46, .72; Dancey & Reidy, 2007) suggesting a strong relationship between multidimensional balance and locomotor competence in youth with VIs. The robustness of this finding was reinforced after controlling for vision level and the presence of a comorbidity ($\rho_{yx1.x2x3}$ = .42, 95% CI = .24, .57). Although causational investigations are needed, these results signify that balance (to some degree) may act as a co-requisite and/or constraint on the locomotor development of youth with VIs. These findings align with results from Metgud and

Honap (2018) who investigated associations between the stork stand, the BESS, and the kicking and jumping skills from the APEAS in youth with VIs (p < .001; BESS: r_{kick} = -.42, r_{jump} = -.33; stork: r_{kick} = .45, r_{jump} = .42). However, it is crucial to note that Metgud and Honap (2018, p. 69) concluded that "there [was] no correlation of static balance with fundamental motor skills in children with visual impairments," even though the values were statistically significant and could be described as strong to moderate in magnitude. Therefore, the subjective posture taken by Metgud and Honap (2018) should be interpreted with caution.

Concerning associations between the individual items of the Brief-BESTest and the locomotor subscale of the TGMD-3, results were mixed. For the TGMD-3, the gallop item had negligible associations with all Brief-BESTest items. Justifications for this outcome were difficult to determine, however, this result could have been due to measurement characteristics found within the Brief-BESTest and the TGMD-3 locomotor subscale (e.g., ordinal scalars, the criteria used for scoring the gallop and the Brief-BESTest items were not compatible possibly due to low task specificity between the tasks). At present, the relationship between the TGMD-3 gallop and the items in the Brief-BESTest in youth with VIs can be described as dubious. All other TGMD-3 items were more promising (i.e., at least two or more moderate associations per item).

For the Brief-BESTest, the Fall-R, Fall-L, and Foam items had negligible to weak associations with all TGMD-3 items. Within youth with VIs, the Foam item was negatively skewed (-4.33) and highly leptokurtic (19.81) highlighting a significant ceiling effect. Therefore, due to the lack of variability, it is unsurprising that the Foam item did not associate with the TGMD-3 items. Likewise, the lack of associations surrounding the

Fall-R and Fall-L items may be due to a lack of variability as both items were somewhat leptokurtic (Fall-R = 1.56; Fall-L = 2.60). Therefore, it is possible that the Foam, Fall-R, and Fall-L items may have not been sensitive enough to produce a significant amount of variability in youth with VIs. Initially, these results suggest that the reactive postural response (Fall-R, Fall-L) and sensory orientation (i.e., Foam) postural systems may have little to nil relationship with TGMD-3 locomotor subscale items. However, the results of this study were limited by the assessments used and the selected population of interest. Therefore, additional investigations are needed.

TGMD-3 items that had the largest associations with the Brief-BESTest items were the skip, which is rhythmically challenging, as well as the run, and the hop, which are both neuromuscularly challenging (e.g., requires strength, power, rapid/dynamic displacement of the center of mass). Likewise, the Single-L (anticipatory postural adjustment; static), UpGo (stability in gait; dynamic), and Reach (stability limits; dynamic) items generally performed best with the TGMD-3 items. Taken together from a monotonic standpoint, it appears the Single-L, UpGo, and Reach items were better related with the more challenging continuous skills of the TGMD-3 (i.e., skip, run, hop). These results were global trends, however, not all bivariate outcomes were statistically significant.

Of the 48 possible zero-order bivariate correlations between the individual Brief-BESTest and TGMD-3 locomotor subscale items, four (8%, $p < .001$) were strong, 13 (27%, $p < .01$) were moderate, nine (19%, $p < .05$) were weak, and 22 (46%, $p > .05$) were negligible. Thus, the hypothesis that all of the correlations between the individual items of the two assessments would be statistically significant ($p < .05$) was not met.

However, hypothesized outcomes can be gleaned from these results. Specifically, the proceeding aspects of this discussion will focus upon the strong and moderate correlations found between certain Brief-BESTest (i.e., Single-L, Single-R, UpGo, Reach, Hip) and TGMD-3 locomotor subscale items (i.e., run, hop, skip, jump, slide).

Single-L/Single-R. The Single-R item moderately correlated with the hop, skip, and jump items. Further, the Single-L item strongly correlated with the hop and skip and moderately correlated with the slide and run items. These results are surprising as both items are static balance tasks which traditionally have not correlated with dynamic tasks in multiple populations. Of specific interest was the Single-L task which had the best overall performance (of all Brief-BESTest items) with the TGMD-3 locomotor subscale items. Unsurprisingly, a large majority of the youth with VIs were right-foot dominant (n = 76, 79%; determined by asking participants which foot they would kick a soccer ball with). It is possible that the it was harder to stay balanced during the Single-L task for a majority of the participants (i.e., non-dominant foot) and therefore, was better at differentiating the monotonic relationship between the single-leg tasks and the TGMD-3 locomotor subscale items. As the Single-R/Single-L items assessed anticipated postural transitions during a static balance task (Horak et al., 2009), it is possible that anticipated postural transitions are also important in more dynamic tasks in youth with VIs.

UpGo. The UpGo item moderately correlated with the hop, skip, and slide items and had the strongest bivariate correlation within the correlation matrix (i.e., run; ρ = .55). This was not surprising as the UpGo item assessed the coordination between locomotor and sensorimotor programs (i.e., stability in gait; Horak et al., 2009). Historically, individuals with VIs have been found to have altered gait strategies (Ray et al., 2007; Pogrund & Rosen, 1989; Rosen, 1989; Sleeuwenhoek et al, 1995) and it is logical to posit that an individual's ambulation strategies (e.g., increased cautiousness: smaller steps, slower walking speed, etc.) could influence and/or constrain locomotor skill development. Additional support for this hypothesis was reinforced by the moderate to strong associations (ρ = .31 to .51) that were found between the UpGo item and a majority of the continuous locomotor tasks in the TGMD-3 locomotor subscale (i.e., run, hop, skip, slide). However, negligible correlations were found between the UpGo item and the gallop (i.e., continuous skill) and the jump (i.e., discrete skill) suggesting additional research is warranted.

Reach. The Reach item had a strong correlation with the skip item and a moderate relationship with the jump and slide items in the TGMD-3. As the Reach item assessed how far youth with VIs were willing to appropriately adjust/control their center of mass while shifting away from their base of support (Horak et al., 2009), it could be suggested that Reach performance represented a proxy measure of the stability-mobility tradeoff (Horvat et al., 2003; Ray, 2004; Ray et al., 2007). Due to the flight phases, coordination, and rhythm needed to complete a continuous skip, it could be suggested that those who were willing to push their limits of mobility (i.e., put themselves in a dynamic, less stable positions) were more likely to be successful at the skip. This could also be true for the slide (although to a lesser degree) as the slide—like the skip—is somewhat rhythmic in nature. However, this relationship was not found in other dynamic continuous items such as the run, gallop, or hop suggesting that different balance systems may be task- or skill-specific. The Reach was also moderately correlated with the jump. Interestingly, both the Reach and jump items are discrete tasks. Further, the jump (if performed correctly) is a ballistic task forcing an individual to accelerate and decelerate (i.e., land) rapidly in the sagittal plane. Therefore, the Reach item may be providing preliminary evidence of a stability-mobility strategy being employed by youth with VIs during the horizonal jump.

Hip. Last, the Hip item which measured functional hip strength/postural alignment during standing (Horak et al., 2009) had a moderate correlation with the run, hop, and skip items in the TGMD-3 locomotor subscale. This finding suggests that when youth with VIs have a pronounced biomechanical constraint during a static task at the hip, such a constraint could become exacerbated during dynamic, rhythmic, and/or neuromuscularly challenging locomotor tasks performed in the sagittal plane. That is, a 'kink in the kinetic/postural chain' during a static task could become more pronounced when transitioning to a more dynamic task.

Conclusion

Based on previous research, balance assessment associations have been highly contentious. One study which previously investigated the associations between balance and other motor skills in youth with VIs only added to the controversy (Metgud & Honap, 2018). However, these findings suggest that total Brief-BESTest and TGMD-3 locomotor subscale scores have a strong monotonic correlation in youth with VIs (i.e., total scores = global balance/locomotor competence). These findings affirm the supposition put forth by Ulrich and Ulrich (1985) who stated that correlational results between balance and locomotor and/or object control skills are likely heavily influenced by balance assessment specificity. As Burton and Davis (1992, p. 17) elaborated, "…although studies suggest that balance is a fairly unified general ability underlying the performance of a variety of movement skills…there also is a considerable amount of research indicating that balance is specific to the task being performed." In line with this conclusion, Reed (1989) stated that isolated environmental contexts and singular mechanisms regarding posture and movement are 'biological fictions.' Regarding the individual item bivariate correlations, the results were less than optimal, however, several interesting findings were uncovered which should provide an impetus for future investigations.

Limitations

One limitation of this study was the use of a convenience sample. Specifically, all youth with VIs were from New York or Florid. Also, it is possible that task novelness (e.g., Reach) or decreased participant motivation influenced the results of this study. Last, it is important to note that these findings were found in youth with VIs, therefore, investigations concerning the relationship between multidimensional balance and locomotor competence in other populations are required.

Implications for Practice

Multidimensional balance in youth with VIs should be viewed as a co-requisite to locomotor skills. Further, it is important for practitioners to acknowledge that specific balance systems may play a more prominent or withdrawn role in different locomotor skills (i.e., inter-task specificity vs. generality). Although the results of this study are correlational, it is reasonable to hypothesize that multidimensional balance can and/or does constrain locomotor development in youth with VIs which could contribute to a negative spiral of disengagement and/or impaired health- and movement-based outcomes (Stodden et al., 2008). However, further investigations are needed. As such, practitioners should actively develop multidimensional balance skills in youth with VIs in tandem with other motor skills. Based on the current sample, practitioners should be aware that lower vision levels and (especially) the presence of a comorbidity may be impactful confounding variables concerning balance and/or locomotor performance.

Table 5.1

Brief-BESTest and TGMD-3 Locomotor Subscale Descriptive Statistics for Youth with VIs

Assessment	*Mean*	*SD*	*Median*	*Skew*	*Kurtosis*	*SE*
Brief-BESTest	15.71	3.27	15	.25	-.77	.33
UpGo	2.79	.41	3	-1.41	.00	.04
Fall-R	1.99	.55	2	-.38	1.56	.06
Fall-L	2.01	.51	2	-.45	2.60	.05
Reach	1.97	.81	2	-.64	.10	.08
Hip	1.47	.92	2	-.40	-.91	.09
Single-R	1.30	.99	1	.42	-.85	.10
Single-L	1.25	.94	1	.54	-.57	.10
Foam	2.93	.30	3	-4.33	19.81	.03
TGMD-3 Loc.	26.29	8.36	27	-.48	-.32	.85
Run	5.08	2.56	6	-.59	-.80	.26
Gallop	4.01	2.40	5	-.59	-.95	.24
Hop	3.32	2.09	3	.40	-.37	.21
Skip	2.90	2.02	4	-.39	-1.24	.21
Jump	4.55	2.26	5	-.17	-.96	.23
Slide	6.43	2.14	7	-1.70	2.37	.22

Table 5.2

Screening of Potential Confounding Variables using Spearman First-order Partial Correlations in Youth with VIs

Variable	Correlation
Sex	.60
Comorbidity	.51
Age-band	.61
BMI%	.61
Vision level	.52

Table 5.3

Zero-order Spearman Correlations for Brief-BESTest and TGMD-3 Locomotor Subscale Items in Youth with VIs

Item	Run	Gallop	Hop	Skip	Jump	Slide
UpGo	.55*** (.39-.68) *Strong*	.10 (-.10, .30) *Negligible*	.31** (.12, .48) *Moderate*	.30** (.11, .47) *Moderate*	.13 (-.07, .32) *Negligible*	.39*** (.20, .55) *Moderate*
Fall-R	.02 (-.18, .22) *Negligible*	.08 (-.13, .27) *Negligible*	.09 (-.11, .28) *Negligible*	.03 (-.18, .22) *Negligible*	.12 (-.09, .31) *Negligible*	.09 (-.11, .28) *Negligible*
Fall-L	.10 (-.11, .29) *Negligible*	.09 (-12, .28) *Negligible*	.02 (-.18, .22) *Negligible*	.13 (-.07, .32) *Negligible*	.18 (-.02, .37) *Negligible*	.21* (.01, .40) *Weak*
Reach	.24* (.04, .42) *Weak*	-.06 (-.26, .14) *Negligible*	.24* (.04, .42) *Weak*	.42*** (.24, .57) *Strong*	.34*** (.15, .51) *Moderate*	.30** (.10, .47) *Moderate*
Hip	.33*** (.14, .50) *Moderate*	.03 (-.17, .23) *Negligible*	.31** (.11, .48) *Moderate*	.31** (.12, .48) *Moderate*	.24* (.04, .42) *Weak*	.25* (.05, .43) *Weak*
Single-R	.24* (.04, .42) *Weak*	.06 (-.15, .25) *Negligible*	.36*** (.18, .53) *Moderate*	.32** (.12, .49) *Moderate*	.35*** (.16, .52) *Moderate*	.26 (.06, .44) *Weak*
Single-L	.32** (.13, .49) *Moderate*	.09 (-.11, .29) *Negligible*	.46*** (.29, .60) *Strong*	.44*** (.26, .59) *Strong*	.25* (.05, .43) *Weak*	.39*** (.21, .55) *Moderate*
Foam	.00 (-.19, .21) *Negligible*	-.09 (-.28, .11) *Negligible*	.02 (-.18, .22) *Negligible*	.23* (.03, .41) *Weak*	.14 (-.05, .33) *Negligible*	.00 (-.21, .19) *Negligible*

Note. Parenthesis are 95% CIs. ρ interpretations are in italics. * = ≤ .05, ** = ≤ .01, *** = ≤ .001

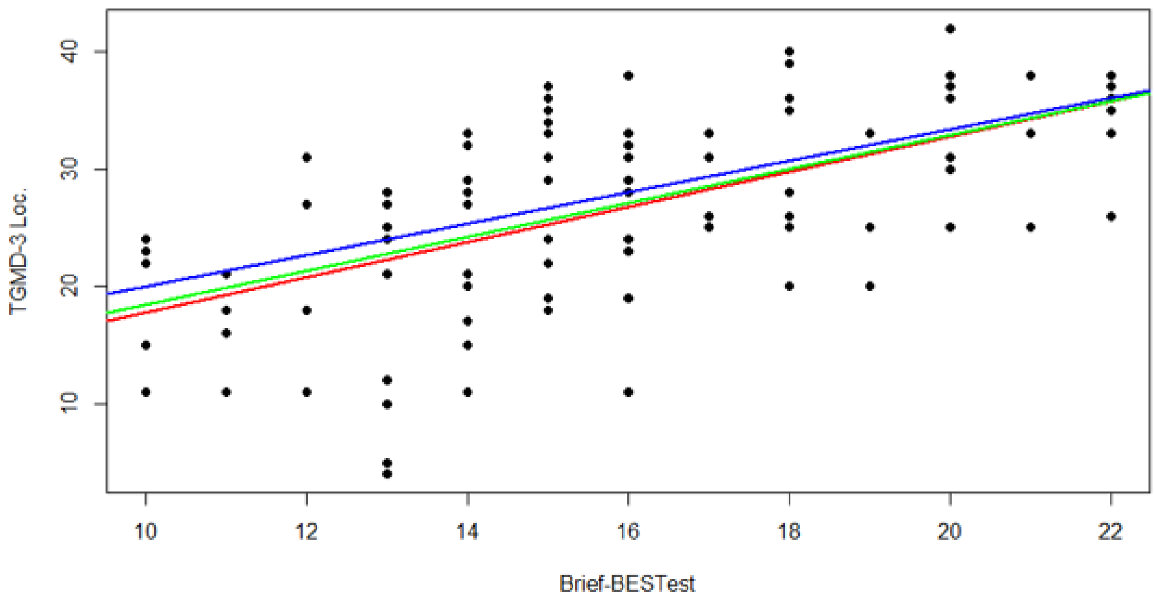

Figure 5.1 Brief-BESTest and TGMD-3 locomotor subscale total score scatterplot in youth with VIs.

Note. Regression models added for illustrative purposes: red = linear (y = 2.74 + 1.50x); green = robust linear (y = 3.93 + 1.45x); blue = quantile (tau = .5; y = 6.67 + 1.33x).

CHAPTER 6

DISCUSSION

The three studies contained within this dissertation contribute to the understanding of multidimensional balance in youth with VIs. Overall, these studies addressed gaps in the literature by examining multidimensional balance (as measured by the Brief-BESTest) in youth with VIs. Specifically, Study 1 examined the construct and convergent validity of Brief-BESTest scores in youth with VIs. Study 2 compared Brief-BESTest scores between youth with and without VIs. Study 3 investigated associations between Brief-BESTest and TGMD-3 locomotor subscale scores in youth with VIs. It is believed that all three studies provided a natural progression of evidence (i.e., Study 1: validation, Study 2: comparison, Study 3: association) which embodied the overall scope of the dissertation.

Vision and Multidimensional Balance

Balance is a task-specific lifespan motor skill that enables human motor development and movement (Assaiante & Amblard, 1995; Burton & Davis, 1992; Haddad et al., 2013; Leversen et al., 2012; Stoffregen, 2016). Although the complexities of balance have led to assessment issues and mixed results within the literature, the construct of multidimensional balance and assessing various operationalized balance systems in youth with VIs (or any other population) seems promising. The results of Study 1 have shown that multidimensional balance can be examined in youth with VIs using the Brief-BESTest which, in turn, could influence current practices and enable a cascade of future research.

Within Study 2, youth with VIs were found to have decreased balance scores compared to youth without VIs. From a physiological standpoint, youth with VIs have two individual constraints which could influence their health- and movement-based trajectories: VI (i.e., structural constraint) and multidimensional balance (i.e., functional constraint) (Newell, 1986; Langley, 2001; Riccio & Stoffregen, 1988). Concerning VIs as a structural constraint, the visual system is known to contribute to balance performance along with proprioceptive and vestibular inputs. However, it has been posited that humans are capable of reweighting sensory information to compensate for sensory deficiencies (Peterka, 2002). Thus, having a VI is a structural constraint that can likely be overcome. Further, it is important to note that vision primarily provides proactive (i.e., feedforwarding) information (Huxham et al., 2001).Therefore, it could be postulated that balance and/or movement situations/tasks that do not inherently rely on feedforwarding (e.g., identifying an icy patch on a sidewalk and averting such a hazard) are less likely to be negatively influenced by the presence of a VI.

Likewise, multidimensional balance is a functional constraint that could be constraining youth with VIs as balance is a co-requisite for movement and skill development. Importantly, as a functional constraint, multidimensional balance can be improved with training (Elsman et al., 2019; Paravlic et al., 2016; Sravani & Metgud, 2014; Suveren-Erdogan, 2018; Suveren-Erdogan et al., 2018) highlighting the importance of motor learning/development for balance performance (Huxham et al., 2001). As balance deficits appear to be common in youth with VIs when compared to their peers, interventions are needed and have the potential to be successful. As youth with VIs are capable as becoming as skilled, active, and/or fit as those without VIs, significant emphases must also be placed on environmental (e.g., accessibility) and sociological barriers as youth can be excluded, have fewer friendships, or have differences in appearance due to their VIs (Sugden & Wade, 2013). Therefore, a major key moving forward appears to be the clever use of a dynamic constraints model (i.e., child resources—environment—task model; Sugden & Wade, 2013).

Study 3 was able to highlight that multidimensional balance is monotonically associated with locomotor competence. This culminating outcome contradicted past conclusions of the role of balance performance on skill/movement (Burton & Davis, 1992; Metgud & Honap, 2018; Ulrich & Ulrich, 1985) thereby providing preliminary evidence to suggest that multidimensional balance may constrain movement- and health-related outcomes in youth with VIs. However, future research is needed.

Last, it is important to note that within Study 2 and 3, both age-band and biological sex were not confounding variables concerning Brief-BESTest scores in youth with VIs. Both age and sex are variables that can be important variables concerning balance performance, especially in younger children (Venetsanou & Kambas, 2011). Yet, in youth with VIs, balance performance has been shown to differ by sex (Johnson-Kraemer et al., 1992), however, such an outcome is atypical as most studies have not found significant differences by sex (Leonard, 1969; Pereira, 1990; Ribadi et al. 1987; Rutkowska et al., 2015). From a developmental perspective, differences in balance performance have been found by age in youth with VIs (Ribadi et al., 1987; Rutkowska et al., 2015) although contradictory findings exist (Pereira; 1990). Thus, given the results of Study 2 and 3, the Brief-BESTest can be used for both sexes and for a wide range of ages (i.e., 8-20 years) which will be helpful for researchers and practitioners who work with youth with VIs who are a low-prevalence population typically requiring age-independent convenience sampling. However, additional research is needed in younger children (i.e.., > 8 years) as younger children typically begin developing adult like postural responses after the age of seven (Nougier et al., 1998; Shumway-Cook & Woollacott, 1985; Woollacott et al., 1989).

Future Research

Concerning youth with VIs, this dissertation has validated a multidimensional balance assessment, provided evidence of balance deficits in multiple systems, and highlighted an association between multidimensional balance and locomotor scores. Therefore, it is suggested that the findings from these three studies should provide an impetus for future investigations as the Brief-BESTest can now be used for observational (e.g., balance profiles), correlational (e.g., health indicators), and experimental (e.g., intervention) studies ideally via random sampling.

Balance as a constraint. As previously described, youth with VIs trend with lower levels of health-related fitness, physical activity, and motor skill competence compared to peers without VIs. As balance is a co-requisite for movement, and balance performance is impaired in youth with VIs, it is plausible that balance could be operating as a functional constraint (Langley, 2001; Newell, 1986) on movement- and health-related trajectories (Stodden et al., 2008). As such, novel investigations should examine balance as a mediating or moderating variable in youth with VIs (e.g., path analysis:

balance → physical activity, motor competence, exercise, and/or recreation → health-related fitness and/or risk factors).

Inter-task specificity. An important finding of Study 3 was that the monotonic relationships between individual Brief-BESTest and TGMD-3 locomotor items were mixed. As such, it should be emphasized that the heterogenous monotonic associations within Study 3 may have been related to measurement issues (i.e., all assessments were limited by their own characteristics and assumptions). Thus, if researchers hope to replicate or extend (e.g., different assessments) the evidence provided within Study 3, it is likely that novel balance and/or locomotor assessments will need to be developed which consider inter-task requirements and specifications (perhaps through task analysis processes). Due to task-specific demands and/or goals, associations between balance and locomotor scores can and will likely continue to be highly variable (as they were in the current sample). However, researchers should maintain that balance systems are likely nested within movement (Reed, 1989). Meaning, lack of association between assessments does not mean a balance system is not enabling and/or contributing to the execution of a suprapostural task in some fashion.

Longitudinal studies/predictive validity. Currently, most studies (including the three studies within this dissertation) surrounding youth with VIs are cross-sectional in nature. Therefore, little is known in regard to the individualized developmental trajectories on youth with VIs across time (a significant limitation within the studies of lifespan motor development, physical activity, and health). Thus, studies that track multidimensional balance in individuals with VIs are needed. To this point, time-series studies that examine the extent to which a multidimensional balance score predicts scores on a criterion measure (e.g., falls, injuries, physical activity) would provide practitioners with valuable heuristics for score interpretation.

Interventions. Balance interventions concerning youth with VIs have not utilized random sampling, randomization, attempted to improve multidimensional, and included retention data. Thus, highly rigorous clinical trials are needed so that cause-and-effect and evidence-based best practices can be established.

Conclusion

This dissertation represented the first studies to (a) examine the construct and convergent validity of Brief-BESTest scores in youth with VIs, (b) compare Brief-BESTest scores between youth with and without VIs, and (c) investigate associations between Brief-BESTest and TGMD-3 locomotor subscale scores in youth with VIs. Results demonstrated that the Brief-BESTest can be adopted by practitioners who work with youth with VIs, that youth with VIs appear to have impaired multidimensional balance performance, and that multidimensional balance is related to locomotor competence in youth with VIs.

From a balance and motor development prospective, youth with VIs appear to lag behind their peers, therefore, proactive screening and assessment should be implemented. Youth with VIs can overcome motor delays in spite of their VIs if adequate motor interventions and/or supports are provided early and perpetually. Thus, these data have the potential to significantly impact balance assessment which could in turn influence (adapted) physical education curricula (e.g., Individualized Education Program goals) or therapeutic/rehabilitative decisions for youth with VIs. Information gleaned from this dissertation suggests that multidimensional balance could be posited as a significant (yet modifiable) mechanism of action which could be constraining health- and movement-based outcomes in youth with VIs.

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