University of Alberta

Concurrent Validity of the

Pediatric Clinical Test of Sensory Interaction for Balance (P-CTSIB)

and the Sensory Organization Test (SOT)

by

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DEDICATION

To Jim,

for always being there for me,

especially through the twists and turns of this rollercoaster ride.

To my parents, Ming and Theresa,

for their loving support and encouragement in all my educational endeavors.

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ABSTRACT

This study evaluated the concurrent validity of the P-CTSIB and the SOT. Test-retest reliability of the P-CTSIB scores obtained 1 week apart was also examined.

Thirty-nine typically developing children participated in the study, eight 3.5-year-olds, sixteen 5.5-year-olds, and fifteen 8-year-olds. A subset of 15 children also participated in the test-retest portion of the study.

The concurrent validity between the two tests ranged from poor to moderate ($r = -.11$ to $-.69$). Test-retest reliability of P-CTSIB scores ranged from poor to fair (ICC = .35 to .47). Based on these results, the P-CTSIB does not appear to be a valid or reliable outcome measure to evaluate sensory system influences on postural control or sensory organization ability in children.

Analysis of anthropometric ratios on P-CTSIB and SOT scores using a step-wise regression analysis suggests that the height / head circumference ratio may be a better predictor of SOT scores than the P-CTSIB.

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CHAPTER 1

INTRODUCTION

Introduction to the Thesis

Children with various types of motor disabilities have postural control difficulties. The ability to maintain postural control is considered to be essential for all functional activity and mobility (Deitz, Richardson, Atwater, Crowe, & Odiorne, 1991; Shumway-Cook & Woollacott, 2001; Westcott, Crowe, Deitz, & Richardson, 1994). Therefore, evaluation of postural control is regarded as an important part of pediatric physical therapy practice (Richardson, Atwater, Crowe, & Deitz, 1992; Westcott, Murray, & Pence, 1998). One challenge in the assessment and treatment of postural control problems is the identification of the specific cause of the problem, given the complexity of factors and systems that influence postural control.

Motor control has been examined by both researchers and clinicians. Theories on how the brain controls movement and posture have evolved. Traditional theories ascribed motor and postural control to hierarchically organized reflex responses in the central nervous system (CNS) triggered automatically by external sensory stimuli (Gesell & Amatruda, 1947; McGraw, 1963; Sherrington, 1906). They postulated that development of movement and stability occurred in a predictable linear sequence dependent upon maturation of the CNS. Newer theories attribute postural control development to the complex and dynamic interaction of many systems (Nashner, 1997; Reed, 1989; Shumway-Cook & Woollacott, 2001; Sugden, 1992). There is increased recognition that motor and postural control is dependent on many factors including those within the child, task constraints, and environmental influences. With the interaction of many systems, normal motor and postural development is now most often described as non-linear and variable (Rine, Rubish, & Feeney, 1998; Shumway-Cook & Woollacott, 1985).

There is a growing emphasis on the use of theory and research to guide practice in rehabilitation. Concurrently, physical therapists have strived to practice evidence-based rehabilitation by increasing the use of reliable and valid outcome measures (Beattie, 2001; Law, 2003). This shift has stimulated the development of new measurement tools to evaluate postural control in children with motor difficulties.

Statement of the Problem

Postural control in children has been evaluated using a variety of methods including non-standardized clinical observations, functional measures, and standardized tests (Crowe, Deitz, Richardson, & Atwater, 1990; Westcott et al., 1998). There are few standardized reliable and valid outcome measures that solely measure postural control. In particular, there is a paucity of clinical outcome measures that examine sensory system influences on postural control (Westcott, Lowes, & Richardson, 1997).

The development of computerized dynamic posturography and the Sensory Organization Test (SOT) introduced a systematic approach to examining visual, somatosensory, and vestibular influences in postural control (Forssberg & Nashner, 1982; Nashner, 1982). However, this test can only be performed using expensive posturography equipment available primarily in large rehabilitation hospitals or research laboratories (Harstall, 1998). It is not feasible to use this equipment in most clinical settings. The Pediatric Clinical Test of Sensory Interaction for Balance (P-CTSIB) was developed as a clinical outcome measure based on the SOT (Crowe et al., 1990; Shumway-Cook & Horak, 1986). The psychometric properties of the P-CTSIB have not been well established. The few studies that have examined reliability of the P-CTSIB have shown only moderate levels of reliability (Crowe et al., 1990; Westcott et al., 1994). There have been no studies examining the concurrent validity of the SOT and the P-CTSIB. It is important to evaluate the psychometric properties of the P-CTSIB further before it is widely adopted as a proxy measure for the SOT.

Aim of the Study

The aim of this study was to evaluate the relationship between the SOT and the P-CTSIB. This information will guide pediatric physical therapists to determine if the P-CTSIB can be used as a reliable and valid outcome measure in a clinical setting, and if it provides the same information as the more sophisticated SOT.

The main objective of the study was to examine the concurrent validity of scores between the P-CTSIB and the SOT in typically developing children. Secondary objectives included (a) examining differences in mean scores on both measures among 3-, 5-, and 8-year-olds; (b) analyzing the influence of anthropometric factors on scores obtained on the SOT and P-CTSIB; and (c) evaluating test-retest reliability of P-CTSIB scores obtained on the same children one week apart.

Overview of the Thesis

The thesis follows a non-traditional format and consists of 3 distinct papers. The first paper, presented in Chapter 2, is a review of the theoretical framework of postural control and research evaluating the sensory system influences on the development of postural control. The second paper, presented in Chapter 3, reports the results of the research study on concurrent validity of the SOT and the P-CTSIB with a sample of typically developing children. The third paper, presented in Chapter 4, reports the test-retest reliability results of the P-CTSIB. Chapter 5 consists of an overall summary of the results, clinical implications, and plans for dissemination of the results. Implications for future research are also addressed in Chapter 5.

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CHAPTER 2

CURRENT THEORIES ON SENSORY SYSTEM INFLUENCES ON THE DEVELOPMENT OF POSTURAL CONTROL

Introduction

Postural control is an integral component of all movement (Westcott, Lowes, & Richardson, 1997). It is defined as the ability of a person to maintain his or her centre of gravity (COG) within the base of support (BOS) to attain desired positions or movement without falling (Horak, 1987; Westcott et al., 1997). Problems with postural control are frequently observed in children with many types of motor disabilities (Westcott et al., 1997), and assessment of postural control is often a major component of physical therapy evaluation of children with motor disabilities. In order to assess postural control in children of different ages, pediatric therapists need to have a thorough understanding of the development of typical postural control.

Theories to explain postural control have changed over the past two decades and continue to evolve with new research findings and methods to measure postural control. Despite new and emerging research in this area, the neural mechanisms of postural control are still not well understood (Shumway-Cook & Woollacott, 2001). Historically, postural control was described using a hierarchical model of motor development. This model assumed posture and motor control were predominantly under the influence of hierarchically organized reflexes and responses in the central nervous system (CNS), and they were elicited automatically by external sensory stimuli (Gesell & Amatruda, 1947; McGraw, 1963; Sherrington, 1906). Changes in postural control were ascribed to maturation of the CNS with the resultant inhibition of primitive reflexes and emergence of more voluntary movement.

Contemporary theories of posture and motor control contend that postural control emerges from a complex, dynamic interaction of many systems within the individual, the task, and the environment (Nashner, 1982; Shumway-Cook & Woollacott, 2001). With increased interest in the influences of the task and the environment on postural and motor control, the role of the sensory systems in identifying and interpreting task components and environmental conditions has been evaluated. Recent research suggests that infants and children use their sensory systems differently than adults and that different sensory processes mature at different rates. These differences contribute to a stage-like, non-linear development of postural control in children. It is important for pediatric physical therapists to consider the developmental level of the child when making judgments on typical or atypical postural control in certain environmental contexts (Westcott et al., 1997). Awareness of sensory influences on postural control may also encourage physical therapists to consider how the sensory systems contribute to postural control dysfunction.

The purpose of this paper is to present current theories on sensory system influences on the development of postural control. In particular, three sensory systems (visual, somatosensory, and vestibular) and three concepts related to these sensory systems (relative weighting, sensory organization, and functional effectiveness) will be discussed. Maturational changes in the use of these systems will also be presented.

Sensory System Influences on the Development of Postural control

The sensory systems provide perception of body position in relation to the task and the environmental context (Nashner, 1982). The sensory systems important for postural control are the visual, somatosensory, and vestibular systems. Each system provides both unique and redundant orientation information about the environment regarding the position of the COG relative to gravity and BOS (Allison & Fuller, 1995; Nashner, 1997b). A person relies on a combination of these three sensory systems to interpret conditions from the environment to maintain their postural control (Allison & Fuller, 1995).

Although the three different sensory systems provide information simultaneously, the CNS appears to rely primarily on information from one sensory system at a time (Nashner, 1982; Shumway-Cook & Horak, 1986). Also, in different contexts, one of the sensory systems may be dominant over the others. In adults, the somatosensory system provides the primary input for postural control in normal stable surface environments. Visual inputs are used if the surface is unstable or under new or unfamiliar situations, and the vestibular system is the final reference in situations when either the visual or the somatosensory system is providing orientationally inaccurate information (Nashner, 1982; Shumway-Cook & Woollacott, 1985). This concept of differential reliance of sensory inputs in varying environments is referred to as *relative weighting* (Woollacott, Debu, & Mowatt, 1987).

In most daily environmental contexts, inputs from the three sensory systems are in agreement with each other. In some situations, however, one or more sensory system may be providing information which does not agree with the others, creating *sensory conflict.*

For example, sensory conflict occurs when a person stands next to a large bus that suddenly moves forward. The visual system indicates backwards sway of the person, but the somatosensory and vestibular systems indicate no movement in relation to gravity. In this situation, the visual system provides *orientationally inaccurate* information. The brain must quickly determine whether the person is indeed falling backwards, or whether the bus is moving forward (Shumway-Cook & Horak, 1986). This process of interpreting information from all three sensory systems, and determining which system is providing the most accurate information, is called *sensory organization* (Forssberg & Nashner, 1982; Nashner, 1997b; Shumway-Cook & Woollacott, 1985; Westcott et al., 1997).

Another concept related to sensory organization and relative weighting of sensory inputs is *functional effectiveness*, which has also been called *functional efficiency* or *level of sensory function* (Cherng, Chen, & Su, 2001; Hirabayashi & Iwasaki, 1995). Functional effectiveness refers to an individual's ability to use input from a particular sensory system for postural control when all other useful sensory inputs are removed or altered (Nashner, 1997a). In other words, functional effectiveness is a measure of the *relative weight* of a specific sensory system in conditions when it is the primary system providing useful information. For example, the functional effectiveness of the somatosensory system can be evaluated by measuring an individual's postural control while he is standing on a stable surface with his eyes closed. The functional effectiveness of the visual system is evaluated by measuring an individual's postural sway while he is standing on an unstable surface with his eyes open. Lastly, the functional effectiveness of the vestibular system is evaluated by measuring an individual's postural sway while he is standing on an unstable surface with his eyes closed. In order to neutralize the effect of individual variation in postural sway, the amount of postural sway in these conditions is compared to the amount of postural sway while standing in the stable surface eyes open condition. A ratio score is then calculated which normalizes postural sway scores across individuals (Figure 2-1). This allows for direct comparison of the functional effectiveness of each sensory system between children and adults of different ages.

The literature examining sensory system influences on postural control suggests there are three important concurrent and interactive developmental processes that occur in children from infancy to adulthood. These processes are (a) the changes in the relative weighting of sensory inputs, (b) the development of sensory organization ability, and (c) the improvement in functional effectiveness of the visual, somatosensory, and vestibular systems (Figure 2-2). Research studies that evaluated one or more of these developmental processes in typically developing children are reviewed. Details describing the sample and the developmental process(es) examined in each study are listed in Table 2-1.

Relative Weighting of the Sensory Systems

The relative weighting of the visual, somatosensory, and vestibular systems is a continuous and flexible process that varies depending on the age of the child, the demands of the task and conditions in the environment (Butterworth & Hicks, 1977; Woollacott et al., 1987). In quiet stance, children below the age of 3 years appear to rely primarily on vision in postural control, followed by somatosensory inputs, and minimally on vestibular inputs (Foster, Sveistrup, & Woollacott, 1996; Riach & Hayes, 1987; Woollacott et al., 1987). As children mature and gain more experience, they progressively use somatosensory inputs more than visual inputs for postural control.

Children over 7 years of age and adults primarily rely on somatosensory inputs (Forssberg & Nashner, 1982; Shumway-Cook & Woollacott, 1985).

The following section examines relative weighting by reviewing findings from four experimental paradigms: (a) moving room experiments, involving only visual perturbations (Figure 2-3); (b) platform rotation experiments, involving only somatosensory perturbations (Figure 2-4); (c) platform translation experiments, involving visual, somatosensory, and vestibular perturbations (Figure 2-5); and (d) steady state experiments, involving no perturbations.

Moving Room Experiments (Visual Perturbation)

Early studies evaluated the role of the visual system in postural control by using a "moving room" experiment. The researchers created a 'visual perturbation' by using a room made up of three walls and a ceiling that could move forward or backward past an infant (Figure 2-3). Lee and Aronson (1974) and Butterworth and Hicks (1977) demonstrated that infants who had recently learned to walk would consistently sway and fall in the direction the room was moved. This illustrated that in the presence of conflicting information, infants were influenced more by altered visual input that indicated postural sway than the accurate somatosensory or vestibular inputs that did not indicate sway. This led these researchers to conclude that visual inputs were more dominant over other sensory inputs for postural control in standing infants.

Foster and colleagues (1996) examined the effect of vision on postural control using the same moving room paradigm. They examined the influence of visual perturbations on standing infants and children from 5 months to 10 years of age. Infants and children were grouped according to functional abilities, which included independent sitters, pull-to-stand infants, new walkers, and three categories of experienced walkers. Parents lightly supported infants below 11 months who could not yet stand independently. These researchers confirmed findings in previous studies that infants and children exhibited a directionally specific postural sway in response to visual perturbations. They further expanded on these findings by reporting a clear developmental trend in the probability and magnitude of sway responses starting in the independent sitters, progressively increasing in the pull-to-stand infants, peaking in the new walkers, then progressively decreasing in the experienced walkers. These findings suggest there is an increase in the dependence on vision as children learn to stand and walk independently and that the reliance on vision decreases with walking experience.

One of the main limitations in these moving room experiments is that only visual inputs were manipulated. Children consistently responded with directionally specific postural sway in response to the visual cues which led the researchers to conclude that visual inputs were dominant over somatosensory and vestibular inputs. While these experiments illustrate that visual cues are important in this context, it cannot be conclusively stated that visual inputs are "dominant" over the other sensory inputs since these were the only dynamic cues children were given that indicated postural sway (Woollacott, Shumway-Cook, & Williams, 1989). For example, it is uncertain how the children would respond if only somatosensory inputs were manipulated.

Another limitation in the Foster et al. (1996) study is that infants below 11 months were provided external support by their parents to maintain standing. The additional support given to the infants significantly changes the demands of the task. The researchers suggested visual dependence in standing progressively increased from the independent sitters and peaked in the new walkers by observing the probability and magnitude of postural sway responses. The researchers, however, acknowledged that these responses might only reflect the change in the amount of external support that was provided to the infants.

Platform Rotations (Somatosensory Perturbation)

Shumway-Cook and Woollacott (1985) addressed the first limitation in the moving room experiments by examining postural responses of standing children who were presented with only somatosensory cues indicating postural sway. They designed an experiment that used a platform capable of producing rotational perturbations around the ankle joint (Figure 2-4) (Shumway-Cook & Woollacott, 1985). In this paradigm, the somatosensory system would detect a postural sway response while visual and vestibular systems would not. Automatic postural reactions were examined by using surface electromyograms (EMGs) to measure activity of the lower extremity muscle synergies. Three of five children aged 15 to 31 months who were tested did not elicit muscle synergy responses to the somatosensory perturbations. These results suggested that children in this age group appear to rely more on visual inputs that did not indicate sway than somatosensory inputs that indicated sway. Five out of six children between 4 to 6 years of age were able to elicit appropriate muscle synergy responses in response to the platform rotations, indicating that children of this age were able to respond to somatosensory cues alone. This led the researchers to hypothesize that children between 4 to 6 years of age were shifting from visual to somatosensory dominance.

Although this study supports the theory that children under 3 years of age primarily rely on vision over other sensory inputs, it is difficult to compare this study with other studies using the moving room paradigm because Shumway-Cook and Woollacott used different outcome measures and examined different postural response components. They analyzed muscle synergy responses using surface EMGs while the other researchers described direction, magnitude, and probability of postural sway responses by observation. Furthermore, none of these studies manipulated visual and somatosensory cues sequentially with the same sample of children to compare how they would respond to the different inputs. There were also small sample sizes in each age category. These studies need to be replicated with larger samples to capture the variability of children's responses.

Platform Translations (Somatosensory, Visual, And Vestibular Perturbation)

Several researchers (Forssberg & Nashner, 1982; Shumway-Cook & Woollacott, 1985; Woollacott et al., 1987) used horizontal platform translations to examine automatic postural responses (Figure 2-5). Visual, somatosensory, vestibular inputs are activated simultaneously when the platform is moved forward or backward in the horizontal plane. Surface EMGs were used in these studies to measure muscle synergies elicited during the automatic postural response.

Forssberg and Nashner (1982) analyzed the postural responses of children from 1.5 to 10 years of age in standing. They concluded that children younger than 7.5 years exhibited greater postural instability in response to the platform translations because their muscle responses were slower and of larger magnitude compared to older children. Shumway-Cook and Woollacott (1985) confirmed these findings in a similar experiment with children from 15 months to 10 years of age. They made an additional unexpected observation that children 4 to 6 years of age generally had slower and more variable

EMG muscle responses than younger children aged 15 to 31 months, and older children aged 7 to 10 years. With the slower and more variable EMG results, one would also expect children 4 to 6 years old to have increased postural sway than children 15 to 31 months old. Analysis of postural sway, however, indicated that children 15 to 31 months old had the greatest amount of sway, followed by children 4 to 6 years-old, and then by children 7 to 10 years old. The researchers acknowledged that this appeared contradictory but they attributed the increased sway in the youngest age group to their overall faster sway rate compared to the two other age groups. Therefore, even though the youngest age group demonstrated faster muscle responses than the 4- to 6-year-olds, this was not adequate to counteract their faster rate of postural sway. Overall, Shumway-Cook and Woollacott concluded that the apparent regression in motor response in the 4- to 6-year-olds suggested that there was a critical transition period in the development of postural control between the 4 and 6 years of age. Based on findings from both the platform rotation and platform translation experiments, the researchers hypothesized that the regression in this transition period may reflect changes in the muscle responses which are indicative of a shift from visual to somatosensory dominance in postural control.

Woollacott and colleagues (1987) also observed automatic postural reactions to anterior and posterior platform translations using surface EMGs in a group of children from 3.5 to 10 years of age. In particular, they examined neck muscle responses while the children were in an upright standing position. They found that children in the 4- to 6-year-old age group had fewer neck muscle responses to anterior sway perturbations (22% of the trials) than children aged 2 to 3 years of age (54% of the trials) or the adults (84% of the trials). The timing of neck muscle responses among 4- to 6-year-old children was also more variable than the other age groups tested. This supports findings from Shumway-Cook and Woollacott's (1985) study that illustrated children from 4 to 6 years old experience a regression which may be indicative of a transition period.

The relative weighting of sensory inputs during the development of postural control was studied further by Woollacott and colleagues by examining differences in the automatic postural reactions of three age groups (2 to 3 years, 4 to 6 years, and 7 to 10 years) in standing with eyes open and their eyes occluded with opaque goggles. The researchers determined that the presence or absence of visual inputs under these conditions could test whether these children relied on vision over the other sensory inputs. They were surprised to discover that 2- to 3-year-olds activated neck muscle synergies faster and more often with their eyes closed than with their eyes open. Furthermore, they determined that 4- to 6-year-olds also activated neck muscle synergies more often *without* vision. The researchers hypothesized that, in normal visual and stable surface conditions, children under 7 years old relied primarily on visual inputs even though they have better postural responses using only somatosensory and vestibular inputs. By 7 years of age, the presence or absence of vision did not appear to impact the speed or frequency of neck muscle responses. This supports the suggestion that the shift from visual to somatosensory dominance had occurred by this age.

One of the limitations in these studies is that the visual, somatosensory, and the vestibular systems all indicate postural sway in response to the horizontal surface translation. It is difficult to determine if differences in muscle response in children between 4 to 6 years of age indicate changes in weighting of the sensory systems. With the exception of the eyes open and eyes closed experiment, these experiments did not selectively tease out the contribution of each of the sensory systems. In addition, surface EMGs evaluate the amplitude and frequency of muscle activation instead of postural sway. Although 4- to 6-year-olds had slower and more variable muscle activation than 15- to 31-month-olds as detected by EMG, this did not result in increased postural sway in the older age group. It is not clear as to what extent muscle activation measured by EMGs is related to the amount of postural sway and whether this measure can reflect differences in postural control among children of different ages.

Steady State (No Perturbation)

Riach and Hayes (1987) analyzed the influence of vision on postural control by examining postural sway in quiet stance with vision present and vision absent. They determined that among children less than 5 years of age who could keep their eyes closed, there was increased postural sway when the children had their eyes open than when they had their eyes closed. This appears to support the findings in the Woollacott study (1987) that children 4 years of age and younger relied primarily on vision to detect postural sway even though reliance on only somatosensory and vestibular inputs resulted in better postural control. It should be noted, however, that this study had a very small sample of children below 5 years of age ($n = 3$).

It is still not fully understood how the weighting of sensory inputs changes as children mature because different experimental paradigms are used in these research studies. Some studies used visual perturbations (Butterworth & Hicks, 1977; Foster et al., 1996; Lee & Aronson, 1974), while others used somatosensory perturbations (Forssberg & Nashner, 1982; Shumway-Cook & Woollacott, 1985; Woollacott et al., 1987), or no perturbations at all (Riach & Hayes, 1987). Riach and Hayes (1987) and Woollacott et al.

(1987) compared postural control of children with their eyes open versus eyes closed whereas other researchers only examined children with their eyes open. Postural control was examined using a variety of outcome measures including observing postural sway responses (Butterworth & Hicks, 1977; Foster et al., 1996; Lee & Aronson, 1974), using surface EMGs to analyze automatic muscle responses (Forssberg & Nashner, 1982; Shumway-Cook & Woollacott, 1985; Woollacott et al., 1987), or using a single force platform to indirectly measure postural sway (Riach & Hayes, 1987). Another potential confounding variable is the external support provided to infants who could not yet stand independently (Foster et al., 1996; Woollacott et al., 1987). These infants may not have had to use automatic postural responses since they had external support. Finally, small sample sizes and lack of statistical analysis in most of these studies contributes to the difficulty in drawing uniform conclusions based on these studies.

With these limitations in mind, the combined literature suggests that children at or below the age of 4 years rely primarily on visual inputs more than somatosensory and vestibular inputs, even when somatosensory inputs may be more accurate and functionally effective. Children who are 7 years of age and older tend to rely primarily on somatosensory inputs over visual and vestibular inputs. The ages of 4 to 6 years appear to represent a transition period when weighting changes from visual to somatosensory dominance. It should be noted, however, that this hypothesis is largely based EMG measurement from two studies with only six or seven children representing the 4- to 6-year-old age group in each study (Shumway-Cook & Woollacott, 1985; Woollacott et al., 1987).

Sensory Organization Ability

The development of sensory organization ability is associated with the age-related changes in the weighting of sensory inputs. As previously discussed, some researchers suggest that young children rely primarily on vision and then begin to rely on somatosensory input between 4 and 6 years of age. This reflects how the weighting of sensory inputs shifts from visual dominance to somatosensory dominance in the development of postural control. Other researchers, however, believe that the shift from visual to somatosensory dominance is not only a reflection of an improvement in the ability to use somatosensory inputs, but also indicative of an improvement in sensory organization abilities during this period (Butterworth & Hicks, 1977; Forssberg & Nashner, 1982; Foster et al., 1996). Without sensory organization ability, young children cannot ignore orientationally inaccurate sensory information and therefore cannot establish the appropriate re-weighting of the sensory systems. For example, using the moving room paradigm, infants fell with the visual perturbation because they could not ignore the visual input that indicated postural sway. They were unable to resolve the sensory conflict between the visual system and the somatosensory and vestibular system. Subsequently, they did not re-weight the sensory inputs appropriately to rely primarily on somatosensory information.

Improved technology led to new methods to systematically measure sensory influences on postural control and to evaluate an individual's sensory organization ability. Nashner and colleagues (Forssberg & Nashner, 1982; Nashner, Black, & Wall, 1982) pioneered techniques to determine the separate contributions of the visual, somatosensory, and vestibular systems under different sensory conditions. A dual force platform system with a movable visual surround which rotated about an axis collinear with the ankle joints was used to create the different conditions. They varied the support surface (fixed and sway-referenced surface) and visual surround conditions (eyes open, eyes closed, and sway-referenced vision) to produce six sensory conditions (Figure 2-6). Conditions 1 and 2 are conditions with congruent sensory information from all three sensory systems. Conditions 3, 4, 5, and 6 are conditions with conflicting sensory information from one or more sensory system. This protocol of six sensory conditions of increasing difficulty is now referred to as the Sensory Organization Test (SOT). The SOT assesses an individual's ability to make effective use of different sensory information for postural control and his or her ability to resolve sensory conflict by ignoring inaccurate sensory information (Nashner, 1997a).

Several researchers studied the development of postural control under these different sensory conditions using laboratory measurements. Discussion is limited to studies that examined differences in steady state postural control as opposed to anticipatory postural control or reactive postural control to platform perturbations in typically developing children, and to studies that tested children in more than two sensory conditions. Seven studies (Cherng et al., 2001; Forssberg & Nashner, 1982; Foudriat, Di Fabio, & Anderson, 1993; Hirabayashi & Iwasaki, 1995; Peterka & Black, 1990; Rine, Rubish, & Feeney, 1998; Shumway-Cook & Woollacott) met these criteria (Table 1).

Forssberg and Nashner (1982) used the SOT to study postural sway reactions in children between 1.5 and 10 years of age. Children above 5 years old maintained their postural control within the limits of stability when visual inputs were absent (Condition 2), when somatosensory inputs were orientationally inaccurate (Condition 4), or both

(Condition 5). Children below 5 years old also maintained their postural control within the limits of stability under Condition 4 (they were not tested in Condition 2 and 5). Children below the age of 7.5 years, however, fell when they were presented with orientationally inaccurate visual inputs together with orientationally inaccurate somatosensory inputs (Condition 6). These results suggested that children below the age of 7.5 years were unable to interpret which inputs provided accurate information. As a result, they were unable to resolve the sensory conflict and to establish appropriate weighting among visual, somatosensory and vestibular inputs. From these results, the researchers hypothesized sensory organization was not well developed in children below 7.5 years of age while children older than 7.5 years old were similar to adults in their postural control.

In another key study examining sensory organization ability, Shumway-Cook and Woollacott (1985) evaluated the postural responses in children ages 4 to 10 years old in four sensory conditions (Condition 1, 2, 4, 5). When the 4- to 6-year-olds were faced with sensory conflict (i.e., Condition 4 and 5) they had marked instability as compared to 7- to 10-year-olds or adults. Most of these children were unable to maintain postural control and subsequently fell. These results also suggested that sensory organization capacities of children below 7 years of age were not fully developed. The researchers hypothesized that, in addition to poor sensory organization, these children continued to depend primarily on vision for postural control. In contrast, all the 7- to 10-year-old children maintained postural control in the conflicting sensory conditions.

Peterka and Black (1990) and Cherng and colleagues (2001) examined age-related changes in postural control using the SOT with children 7 years and older and adults.

Peterka and Black found that children 7 to 15 years old displayed significantly increased postural sway in conditions that presented orientationally inaccurate somatosensory information (Conditions 4, 5, 6) compared to adult responses. They suggested that adult performance was not fully attained until 20 years of age in these conditions. Cherng and colleagues also reported that children 7 to 10 years of age exhibit significant differences compared to adults when somatosensory input was unreliable. These two studies differ from the previous studies that concluded that children over 7 years demonstrated adult-like responses (Forssberg & Nashner, 1982; Shumway-Cook & Woollacott, 1985).

Although all these researchers examined steady state balance using SOT conditions, the protocols of the studies vary widely. Duration of stance in each trial ranged from 5 seconds (Shumway-Cook & Woollacott, 1985) to 50 seconds (Forssberg & Nashner, 1982). Shumway-Cook and Woollacott (1985) tested children under 4 conditions instead of 6 conditions. Different methods were used to measure postural sway including direct measurement using potentiometers (Forssberg & Nashner, 1982; Peterka & Black, 1990; Shumway-Cook & Woollacott, 1985) and indirect measurement using a single force platform (Cherng et al., 2001). Cherng and colleagues also used a paper dome and foam instead of a visual surround and a movable support surface to alter sensory information. The development of the Smart Balance Master system and the EquiTest system by NeuroCom International Inc. (Clackamas, Oregon, U.S.) offered standardized procedures of the Sensory Organization Test (SOT) and simplified the interpretation of results.

Foudriat and colleagues (1993) used the SOT with the NeuroCom EquiTest system with children 3 to 6 years of age. Children 3 and 4 years of age had significantly less postural control in Conditions 1 and 2 compared to children 5 and 6 years of age. These researchers suggested there was a step-like increase in equilibrium scores between the fourth and fifth year of age which supported the premise that postural control in these conditions did not develop linearly. Foudriat et al. also determined that only 5-year-olds exhibited a significant difference between the eyes-open condition (Condition 1) and the eyes-closed condition (Condition 2) with increased stability with eyes open. This appears to contradict findings from Riach and Hayes (1987) and Woollacott and colleagues (1987) who found that children under 5 years or between 4 and 6 years were more stable with their eyes closed than their eyes open.

In this study, the researchers determined that there was significant improvement in the postural control of 6-year-old children compared to all age groups in Condition 3, 4, and 6 which illustrates an increased ability of 6-year-olds to resolve sensory conflict over the other age groups. There were no other significant differences between age groups in the other conditions. They also found that 16 out of 21 three-year-olds could maintain their postural control in all sensory conditions, indicating that children as young as 3 years old were able to ignore orientationally inaccurate visual and somatosensory information and were starting to develop sensory organization ability. This finding suggests the transition period starts earlier at 3 years versus 4 to 6 years as reported by Shumway-Cook and Woollacott (1985).

The development of sensory organization ability appears to mirror the changes in relative weighting of sensory inputs in children (Figure 2-2). These concepts are certainly linked as the appropriate weighting of the sensory inputs depends on the ability to determine whether all three sensory systems are providing congruent and orientationally accurate information. If information is incongruent, an individual relies on his or her sensory organization skills to determine which sensory inputs to use and which sensory inputs to ignore. Findings from the studies examining sensory organization using the SOT appear to support the same transition periods indicated by previous studies examining relative weighting of sensory inputs. Sensory organization ability seems to develop as early as 3 to 4 years of age. Some researchers contended that sensory organization ability reaches adult levels by approximately 7 years of age (Forssberg & Nashner, 1982; Shumway-Cook & Woollacott, 1985). Other researchers determined this ability continues to develop above age 7 and does not reach adult levels until 20 years of age (Cherng et al., 2001; Peterka & Black, 1990). This disagreement in the upper age limit may be due to the different ages examined in the separate studies. Only Peterka and Black (1990) included children above the age of 10 years to examine sensory organization ability. In addition, different criteria were used to indicate maturity of sensory organization abilities. Shumway-Cook and Woollacott (1985) and Forssberg and Nashner (1982) determined children had mature sensory organization abilities when they were able to maintain standing within the limits of stability and not fall in the conditions presenting sensory conflict. Cherng and Peterka compared quantitative postural sway measurements between children and adults. They determined sensory organization ability was mature when there were no significant differences between the postural sway of children and adults.

Functional Effectiveness of the Visual, Somatosensory, and Vestibular Systems

Functional effectiveness of the sensory inputs is another method to analyze sensory influences on the development of postural control. As previously mentioned, functional effectiveness refers to an individual's ability to use input from a particular sensory system for postural control in conditions where it is the primary system providing useful information. Use of the respective ratio scores provides a relative measure of the functional effectiveness of each of the sensory systems (Figure 2-1). The following studies compare mean ratio scores of children to mean ratio scores of adults to determine if the functional effectiveness of a particular sensory system is mature.

Hirabayashi and Iwasaki (1995) performed the SOT using the NeuroCom EquiTest system with children between 3 and 15 years of age and adults between 20 and 60 years of age. They found the somatosensory ratio was similar to adult levels by 3 to 4 years of age. The visual ratio was similar to adult levels by 14 to 15 years of age. The vestibular ratio, however, did not reach adult levels even by 14 to 15 years old. These results illustrate the stage-like developmental progression of how children are able to use information from different sensory systems. This study provides further support that postural control continues to develop beyond adolescence.

Rine and colleagues (1998) collected SOT scores of children 3 to 7.5 years old and adults using the NeuroCom Balance Master system. They also used ratio scores to evaluate how effectively information from each sensory input is used in postural control. With the exception of the visual ratio, however, the ratios used in this study differ from other studies and to those described by NeuroCom International Inc. (2001). Somatosensory function was represented by Condition 3 / Condition 1 and vestibular function was represented by Condition 6 / Condition 1. Like Hirabayashi and Iwasaki, they concluded that there is a stage-like maturation in how inputs from different sensory systems are used in postural control. They found maturation of somatosensory function was complete by 6 years old but visual function and vestibular function were not yet mature by 7.5 years old. The difference in age of maturation of somatosensory function from Hirabayashi and Iwasaki's study may reflect the use of a different ratio in this study. Nonetheless, these results provide further evidence that the functional effectiveness of the visual and vestibular systems continues to develop beyond the age of 7.5 years.

Cherng and colleagues (2001) examined the functional effectiveness of the three sensory systems using ratio scores in 17 children (7 to 10 years old) and 17 adults (19 to 23 years old). Although they used the same ratio scores as Hirabayashi and Iwasaki (1995), they used different equipment and materials to perform the SOT. The researchers created the six sensory conditions by adapting the SOT with the use of materials similar to those suggested by Shumway-Cook and Horak (Shumway-Cook & Horak, 1986). Instead of using the visual surround and movable support surface to alter sensory inputs in Conditions 3 to 6, they used a paper dome and a piece of medium density foam. They also used a single force platform to measure postural sway instead of the Smart Balance Master or EquiTest systems. Cherng et al. determined that there were no significant differences in the visual and somatosensory ratios between 7- to 10-year-old children and adults. The vestibular ratio of the children, however, was significantly different compared to adults ($p < .006$). In addition, the postural sway measurements differed significantly ($p < .05$) between the children and adults under the two conditions where the vestibular system alone was providing orientationally accurate sensory information (Conditions 5 and 6). These results suggested that the functional effectiveness of somatosensory and visual inputs in children had reached adult levels by 7 to 10 years of age, but the functional effectiveness of vestibular inputs was not complete by this age. The contrary findings of the functional effectiveness of the visual inputs from the two previous studies may reflect the use of different materials in this study. The visual ratio is determined by Condition 4 / Condition 1. These children may have had better postural control standing on foam instead of a movable support in Condition 4. This would explain why the visual ratio of these children was not significantly different from adults.

Summary

This paper presents three concurrent and interactive processes involved in the development of postural control in children; changes in the relative weighting of sensory inputs, development of sensory organization ability, and improvement in functional effectiveness of each sensory system. The processes are interrelated and it is artificial to discuss them separately.

Figure 2-2 depicts these three sensory processes, the ages when developmental changes in these processes occur, and the research studies which provide evidence for these developmental changes. Findings in the literature support suggestions that postural control develops in a non-linear, stage-like manner under different sensory conditions. This non-linear development may be related to changes that occur in these three processes from infancy to adulthood.

As infants learn to stand and walk, they rely primarily on the visual system to interpret their body position in space relative to the environment. A critical transition period is hypothesized to occur in children between the ages of 4 to 6 years of age. Several studies, however, indicate this transition period may start as early as 2 or 3 years of age (Foster et al., 1996; Foudriat et al., 1993; Rine et al., 1998; Woollacott et al., 1987). During this transition period, children begin to shift from primarily relying on their visual system to relying more on their somatosensory system. This may be related to emerging sensory organization ability. Children between these ages also start to resolve sensory conflict when they are presented with orientationally inaccurate visual and / or somatosensory information. In addition, functional effectiveness of somatosensory inputs reaches adult levels around 3 to 4 years of age which also enables accurate interpretation of these inputs for postural control. This illustrates the interconnectedness of these three processes since the maturation of functional effectiveness of somatosensory inputs appears to coincide with the shift in weighting to somatosensory inputs and the emerging ability to resolve sensory conflict.

Effective use of visual and vestibular inputs does not appear to reach adult levels until adolescence or early adulthood. Similarly, sensory organization ability continues to develop past the age of 7 to early adulthood. This provides support that functional effectiveness of the these sensory systems is linked to the ability to accurately interpret conditions in the environment and perform appropriate re-weighting of the sensory inputs using sensory organization skills. It is interesting to note, however, that children under the age of 4 years primarily rely on visual inputs even though somatosensory inputs may be more reliable and functionally effective. This seems contrary to contemporary theories that view motor development as a process of self-organization and selection of the most effective and efficient movement strategies (Hadders-Algra, 2000; Helders et al., 2003). One possible explanation may be that children, like adults, depend primarily on their vision when learning new tasks or when they are exposed to novel or unfamiliar environments (Nashner et al., 1982; Shumway-Cook & Woollacott, 1985; Westcott & Burtner, 2004). There is a tremendous acquisition of new motor skills in children less than 4 years old. These infants and toddlers may be constantly learning new tasks and exploring new environments in daily activities.

The explanation for the stage-like developmental progression of postural control and the relative importance of visual, somatosensory, and vestibular inputs remains controversial and not well understood (Forssberg & Nashner, 1982; Sugden, 1992). Postural control, and its importance in functional mobility, is complex. The concepts and hypotheses presented in this review are largely based on a small body of research. Further research using similar experimental protocols, standardized equipment, and larger sample sizes is warranted to further understand these sensory processes in the development of postural control.

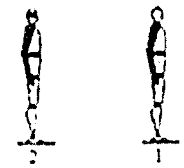
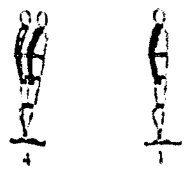
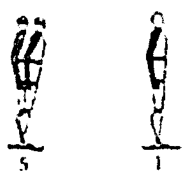
Sensory System	Test Conditions	Ratio Pair	Significance
Somatosensory		Condition 2 / Condition 1	Question: Does sway increase when visual cues are removed? Low scores: Individual makes poor use of somatosensory references.
Visual		Condition 4 / Condition 1	Question: Does sway increase when somatosensory cues are inaccurate? Low scores: Individual makes poor use of visual references.
Vestibular		Condition 5 / Condition 1	Question: Does sway increase when visual cues are removed and somatosensory cues are inaccurate? Low scores: Individual makes poor use of vestibular cues, or vestibular cues unavailable.

Figure 2-1. Functional effectiveness ratios

Note. From *EquiTest System version 8.0 data interpretation manual* (p. 1-3), by NeuroCom International Inc., 2001, Clackamas, OR: NeuroCom International Inc. Copyright 2001 by NeuroCom International Inc. Adapted with permission.

Sensory Processes	Age (years): ≤1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20	Supporting Studies
Relative weighting (dominant sensory system)	Vision → transition → Somatosensory →	(Butterworth & Hicks, 1977; Forssberg & Nashner, 1982; Foster et al., 1996; Lee & Aronson, 1974; Riach & Hayes, 1987; Shumway-Cook & Woollacott, 1985; Woollacott et al., 1987)
Sensory organization ability	No → emerging → Yes →	(Cherng et al., 2001; Forssberg & Nashner, 1982; Foudriat et al., 1993; Peterka & Black, 1990; Shumway-Cook & Woollacott, 1985)
Functional effectiveness (age of maturation)	Somatosensory → Vision → Vest.	(Cherng et al., 2001; Hirabayashi & Iwasaki, 1995; Rine et al., 1998)

Figure 2-2. Three sensory processes occurring in children from infancy to adulthood

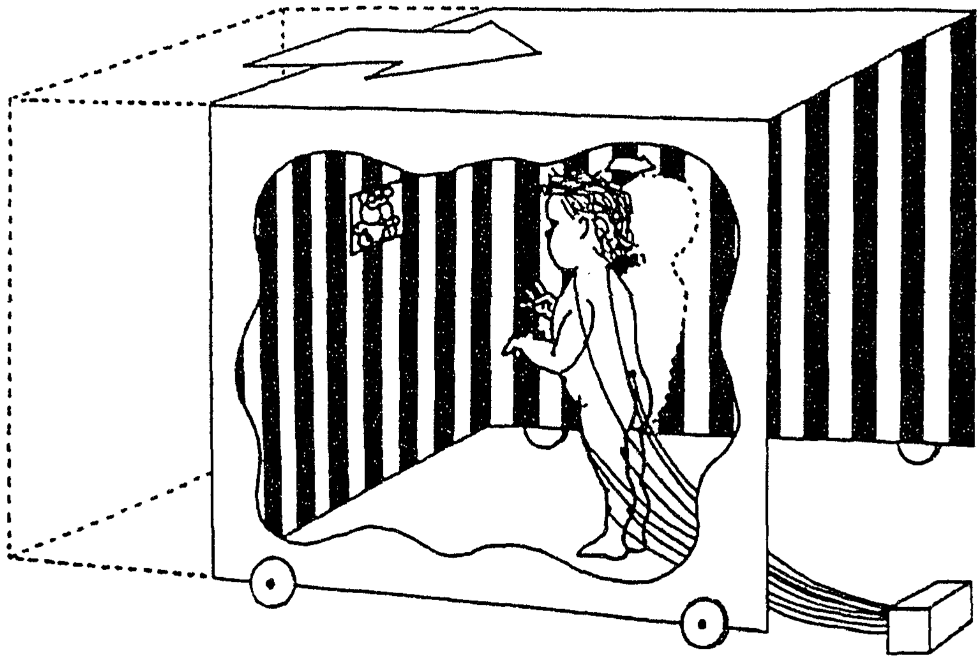


Figure 2-3. Moving room experiment (visual perturbation)

Note. From "Transitions in visual proprioception: A cross-sectional developmental study of the effect of visual flow on postural control," by E. Foster, H. Sveistrup, and M. Woollacott, 1996, *Journal of Motor Behavior, 28*(2), p. 103. Copyright 1996 by Heldref Publications. Reprinted with permission.

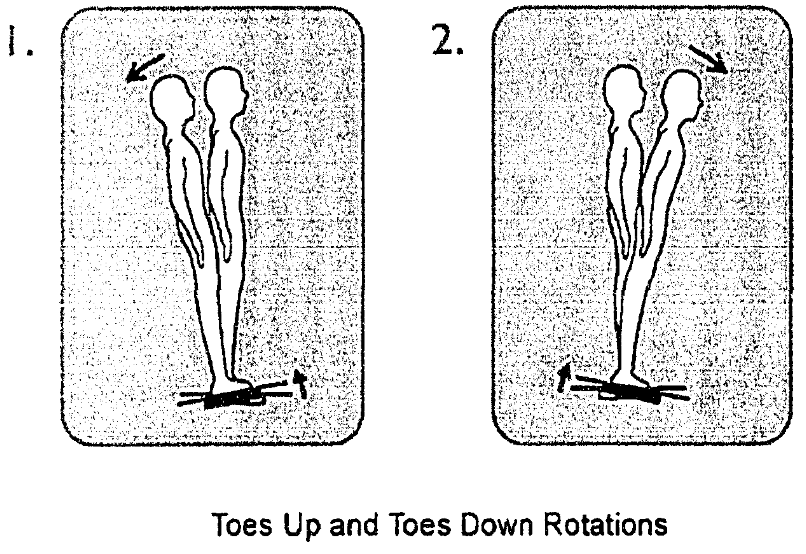


Figure 2-4. Platform rotations (somatosensory perturbation)

Note. From NeuroCom International Inc. (2005) *Computerized dynamic posturography protocols* [http://www.onbalance.com/program/role/cdp/protocols.aspx]. Clackamas, OR: NeuroCom International Inc. Copyright 2005 by NeuroCom International Inc. Reprinted with permission.

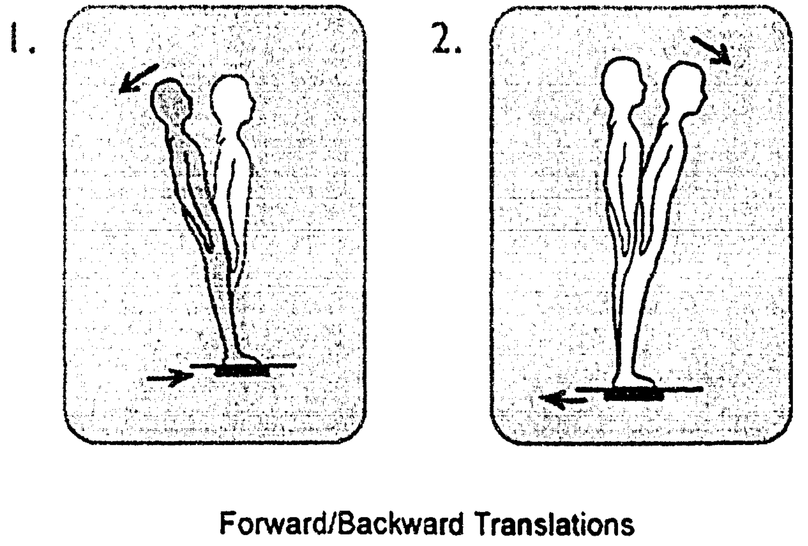


Figure 2-5. Platform translations (somatosensory, visual, and vestibular perturbation)

Note. From NeuroCom International Inc. (2005) *Computerized dynamic posturography protocols* [http://www.onbalance.com/program/role/cdp/protocols.aspx]. Clackamas, OR: NeuroCom International Inc. Copyright 2005 by NeuroCom International Inc. Reprinted with permission.

Condition	Diagram	Description	Orientationally Accurate Sensory Systems	Absent or Inaccurate Sensory Systems
Condition 1		Eyes Open Fixed Surface	Vision Somatosensory Vestibular	
Condition 2		Eyes Closed Fixed Surface	Somatosensory Vestibular	Absent Vision
Condition 3		Sway-Referenced Vision Fixed Surface	Somatosensory Vestibular	Inaccurate Vision
Condition 4		Eyes Open Sway-Referenced Surface	Vision Vestibular	Inaccurate Somatosensory
Condition 5		Eyes Closed Sway-Referenced Surface	Vestibular	Absent Vision Inaccurate Somatosensory
Condition 6		Sway-Referenced Vision Sway-Referenced Surface	Vestibular	Inaccurate Vision Inaccurate Somatosensory

Figure 2-6. Six sensory conditions of the Sensory Organization Test (SOT)

Note. From NeuroCom International, Inc. (1999). *Sensory Organization Test (SOT): sensory analysis* [Brochure]. Clackamas, OR: NeuroCom International, Inc. Copyright 1999 by NeuroCom International, Inc. Adapted with permission.

Table 2-1

Summary of Participants and Sensory Process Examined

Study	**Total number of participants**	**Participants (ages, *n*)**	**Sensory Process Examined in Study**
Lee and Aronson (1974)	7 children	13 – 16 months (1 – 22 weeks of walking experience)	relative weighting
Butterworth and Hicks (1977)	12 children	12.5 – 17.5 months (0.5 – 6.5 months of walking experience)	relative weighting
Foster, Sveistrup, and Woollacott (1996)	34 children, 5 adults	i) 5 – 8 months, *n* = 5 (ISit) ii) 8 – 10 months, *n* = 6 (PS) iii) 11 – 14 months, *n* = 9 (NW < 3 months of walking experience) iv) 2 – 3 years, *n* = 5 (EW1) v) 4 – 6 years, *n* = 5 (EW2) vi) 7 – 10 years, *n* = 4 (EW3) v) adults, 20 – 29 years, *n* = 5 (YA)	relative weighting
Shumway-Cook and Woollacott (1985)	21 children	i) 15 – 31 months, *n* = 5 ii) 4 – 6 years, *n* = 6 iii) 7 – 10 years, *n* = 6	relative weighting sensory organization
Forssberg and Nashner (1982)	18 children	i) 1.5 – 3.5 years, *n* = 4 ii) 3.5 – 5 years, *n* = 4 iii) 5 – 7.5 years, *n* = 6 iv) 7.5 – 10 years, *n* = 3	relative weighting sensory organization
Woollacott, Debu, and Mowatt (1987)	25 children 15 adults	i) 3.5 – 5 months, *n* = 4 ii) 8 – 14 months, *n* = 3 iii) 2 – 3 years, *n* = 7 iv) 4 – 6 years, *n* = 7 v) 7 – 10 years, *n* = 11 vi) adults, 22 – 47 years, *n* = 15	relative weighting

Riach and Hayes (1987)	76 children	i) 2 – 4 years, $n = 7$ ii) 5 – 6 years, $n = 10$ iii) 7 – 8 years, $n = 10$ iv) 9 – 10 years, $n = 15$ v) 11 – 12 years, $n = 19$ vi) 13 – 14 years, $n = 15$	relative weighting
Peterka and Black (1990)	48 children 166 adults	i) 7 – 12 years, $n = 21$ ii) 13 – 19 years, $n = 27$ iii) 20 – 29 years, $n = 28$ iv) 30 – 39 years, $n = 32$ v) 40 – 49 years, $n = 32$ vi) 50 – 59 years, $n = 26$ vii) 60 – 69 years, $n = 35$ viii) > 70 years, $n = 13$	sensory organization
Cherng, Chen, and Su (2001)	17 children, 17 adults	i) 7 – 9 years, $n = 17$ ii) adults, 19 – 23 years, $n = 17$	sensory organization functional effectiveness
Foudriat, Di Fabio, and Anderson (1993)	82 children	i) 3 years, $n = 21$ ii) 4 years, $n = 21$ iii) 5 years, $n = 20$ iv) 6 years, $n = 20$	sensory organization
Hirabayashi and Iwasaki (1995)	112 children 26 adults	i) 3 – 4 years, $n = 12$ ii) 5 – 6 years, $n = 21$ iii) 7 – 8 years, $n = 18$ iv) 9 – 10 years, $n = 22$ v) 11 – 13 years, $n = 20$ vi) 14 – 15 years, $n = 19$ vii) adults (ages not specified), $n = 26$	functional effectiveness
Rine, Rubish, and Feeney (1998)	23 children	i) 3 – 4 years, $n = 6$ ii) 4 – 6 years, $n = 5$ iii) 6 – 7.5 years, $n = 12$	functional effectiveness

Note. n = number of children in each age group; ISit, independent sitters; PS, pull-to-stand infants; NW, new walkers; EW, early walkers; YA, young adults.

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CHAPTER 3

CONCURRENT VALIDITY OF THE P-CTSIB AND THE SOT

Introduction

Children with motor disabilities frequently exhibit postural control dysfunction (Westcott, Lowes, & Richardson, 1997). A survey of pediatric physical therapists indicated that more than 87% of respondents "often," "very often," or "always" worked on sitting and standing balance goals with their clients (Westcott, Murray, & Pence, 1998). Physical therapists frequently emphasize postural control in their intervention strategies because it is viewed as an essential component of all movement (Westcott et al., 1997).

Contemporary theories of posture and motor control contend that postural control is achieved by the interaction of many systems within the person and the demands of the specific task and environment (Shumway-Cook & Woollacott, 2001; Westcott et al., 1997). Within the person, biomechanical, motor, and sensory systems are considered important systems that influence postural control (Horak, 1987; Nashner, 1997b; Westcott et al., 1997).

In the clinical setting, postural control is often assessed using non-standardized clinical observation (Westcott et al., 1998) with an emphasis on the biomechanical and motor systems. Therapists note whether there is decreased balance in sitting or standing, describe the size of base of support, and observe the presence or absence of equilibrium and protective reactions. Therapists often ask a child to stand on one leg, to walk across a balance beam, or to stand on a tilt board to test the effect of decreasing the base of support or introducing an unstable support surface. Specific balance items or subscales on motor scales such as the Peabody Developmental Motor Scales (Fewell & Folio, 2000) and the Bruininks-Oseretsky Test of Motor Proficiency (Bruininks, 1978) are also used to assess balance clinically. None of these clinical assessments assess the sensory influences on postural control.

Visual, somatosensory, and vestibular inputs provide orientation information relative to environmental conditions, and enable a person to generate appropriate postural responses within the external context (Nashner, 1982). These sensory systems are critical for a person to interpret elements of a particular task and conditions in the environment in order to determine the postural control requirements.

Recent research suggests that infants and children use their sensory systems differently compared to adults, and that sensory influences on postural control develop in a stage-like, non-linear fashion. In quiet stance in stable environment conditions, children younger than 3 years appear to rely primarily on vision for postural control, followed by somatosensory inputs, and minimally on vestibular inputs (Foster, Sveistrup, & Woollacott, 1996; Riach & Hayes, 1987; Woollacott, Debu, & Mowatt, 1987). As children mature and gain more experience, they progressively use somatosensory inputs more than visual inputs for postural control. Children over 7 years of age and adults primarily rely on somatosensory inputs (Forssberg & Nashner, 1982; Shumway-Cook & Woollacott, 1985), followed by visual inputs, and minimally on vestibular inputs. Throughout the lifespan, the vestibular system generally functions as a final reference when visual and somatosensory information is absent or unreliable. Some researchers report that in conditions where a person can only accurately rely on vestibular system inputs, postural control is not fully mature until adolescence or adulthood (Cherng, Chen,

& Su, 2001; Peterka & Black, 1990). This observation is contrary to previous studies that concluded adult-like responses were attained by children over 7 years (Forssberg & Nashner, 1982; Shumway-Cook & Woollacott, 1985).

Children also differ from adults in their sensory organization ability. Sensory organization refers to the process of interpreting information from all three sensory systems and determining which system is providing the most accurate information in order to maintain postural control (Forssberg & Nashner, 1982; Shumway-Cook & Woollacott, 1985; Westcott et al., 1997). In most everyday environments involving stable visual and surface conditions, the inputs from the three sensory systems are in agreement with each other. In some environments, however, a person may receive inaccurate visual or somatosensory information, thus creating *sensory conflict* between the three sensory systems. Current research indicates that children, particularly those below 7 years of age, have more difficulty than adults ignoring inaccurate sensory information, and they exhibit decreased sensory organization ability (Forssberg & Nashner, 1982; Foudriat, Di Fabio, & Anderson, 1993; Shumway-Cook & Woollacott, 1985).

A critical transition period in how children use sensory system inputs for postural control is hypothesized to occur between the ages of 4 to 6 years (Shumway-Cook & Woollacott, 1985; Shumway-Cook & Woollacott, 2001). During this transition period, children begin to shift from primarily relying on their visual system to relying more on their somatosensory system. It is also the period when sensory organization ability emerges.

Other factors contributing to this transition phase may be related to a period of rapid growth that occurs in children between these ages. The changes in the body proportions of children at this time may contribute to changes in their postural control (Shumway-Cook & Woollacott, 2001; Westcott & Burtner, 2004; Woollacott, Shumway-Cook, & Williams, 1989). Other researchers support this suggestion by indicating that, other than age, height was the best predictor of postural control on several balance tests including a modified version of the SOT among children 5 to 10 years of age (Bhattacharya, Shukla, Dietrich, Bornschein, & Berger, 1995); and the Functional Reach Test (FRT) (Duncan, Weiner, Chandler, & Studenski, 1990), Timed Up and Go (TUG) (Podsiadlo & Richardson, 1991), and two subtests of the Bruininks Oseretsky Test of Motor Proficiency (BOTMP) (Bruininks, 1978) among children 5 to 7 years of age (Habib & Westcott, 1998).

It is important for pediatric physical therapists to consider the developmental level of a child when making judgments on typical or atypical postural control in certain environmental contexts (Westcott et al., 1997). An understanding of the influences of sensory conditions and anthropometric factors on postural control may assist physical therapists in determining factors that contribute to postural control dysfunction.

Until the development of the Sensory Organization Test (SOT) (Forssberg & Nashner, 1982; Nashner, 1982, 1997a), no objective test was available to systematically evaluate the influence of somatosensory, visual, and vestibular inputs on postural control. The SOT has been used extensively in research (Allum & Shepard, 1999; Cherng et al., 2001; Forssberg & Nashner, 1982; Nashner, 1982; Peterka & Black, 1990), and it has become the "gold standard" for the objective measurement of the visual, somatosensory, and vestibular inputs that affect postural control (El-Kashlan, Shepard, Asher, Smith-Wheelock, & Telian, 1998; Gabriel & Mu, 2002; Keshner, 1994). The SOT systematically measures the influence of the three sensory systems by measuring the amount of postural sway under six sensory conditions (Figure 3-1). These six conditions represent combinations of three visual (eyes open, eyes closed, or altered using a sway-referenced visual surround) and two support surface variables (flat surface or on a sway-referenced surface). Sway-referencing refers to having the visual surround or support surface move in a 1:1 ratio according to the subject's postural sway (Nashner, 1997a). The six sensory conditions include (a) eyes open, flat surface (Condition 1); (b) eyes closed, flat surface (Condition 2); (c) sway-referenced visual surround, flat surface (Condition 3); (d) eyes open, sway-referenced surface (Condition 4); (e) eyes closed, sway-referenced surface (Condition 5); and (f) sway-referenced visual surround, sway-referenced surface (Condition 6).

The SOT requires the use of specialized and expensive dynamic posturography equipment inaccessible to most pediatric physical therapists. The Pediatric Clinical Test of Sensory Interaction for Balance (P-CTSIB) (Crowe, Deitz, Richardson, & Atwater, 1990; Shumway-Cook & Horak, 1986) was later developed as a clinical alternative to the SOT using inexpensive, readily available materials. The P-CTSIB uses a visual conflict dome constructed from a paper lantern instead of the sway-referenced visual surround, and an 18" X 18" X 3" piece of medium density T-foam instead of the sway-referenced surface to create the six sensory conditions (Figure 3-2). It can be easily administered by physical therapists in a clinical setting. The concurrent validity of the scores obtained by children on the SOT and the P-CTSIB has not yet been investigated. One research study (El-Kashlan et al., 1998) reported the concurrent validity of the SOT with the Clinical Test of Sensory Interaction for Balance (CTSIB) (Shumway-Cook & Horak, 1986), the adult version of the P-CTSIB. The authors reported correlations of .45 at baseline, .74 at 1 month, .89 at 2 months, and .41 at 3 months between composite SOT scores and composite CTSIB scores in 35 adults with vestibular dysfunction.

The P-CTSIB offers clinicians a method to evaluate children's use of their sensory systems to maintain postural control under specific conditions. Clinicians can also use this test to examine children's ability to resolve sensory conflict. It is assumed that the P-CTSIB can be used as a proxy for the SOT, but the relationship of the scores obtained on both tests needs to be evaluated. The main objective of this research study was to examine the concurrent validity of scores obtained by typically developing children on the P-CTSIB and the SOT. Secondary objectives include (a) examining differences in mean scores on both measures among 3-, 5-, and 8-year-olds; and (b) analyzing the influence of anthropometric factors on scores obtained on the SOT and P-CTSIB.

Methods

We used a cross-sectional study design with a volunteer sample, recruiting children who were 3.5, 5.5, and 8 years old in order to examine developmental changes over the three age groups. Three and a half years was chosen as the youngest age group after pilot testing confirmed that children younger than this age had difficulty completing the test protocol. We recruited children by advertising in child care centres, recreational facilities, community centres, and a local community newspaper. Inclusion criteria were that a child's age was within a 6-month upper range for each specified age group. For example, children in the 3.5-year-old age group ranged from the age of 3 years 6 months to 3 years 11 months; children in the 5.5-year-old age group ranged from the age of 5 years 6 months to 5 years 11 months; and children in the 8-year-old age group ranged from the age of 8 years 0 months to 8 years 5 months. Parents also had to commit to attending an evaluation session at a local rehabilitation hospital. Exclusion criteria were (a) a history of current or previous ear infections in the past 6 months; (b) any diagnosed disorders including motor impairment, cognitive impairment, developmental delay, uncorrected visual impairment, or uncorrected hearing impairment; (c) a history of receiving therapy services for postural control difficulties from an occupational, physical, or speech therapist; and (d) strength and range-of-motion values outside typical values determined by a pre-assessment screening process adapted from Habib and Westcott (1998). No child who volunteered and met these criteria was excluded from the study. The study received ethical approval from the Health Research Ethics Board at the University of Alberta. Parents provided written informed consent for their child's participation. Children's assent was obtained prior to testing.

Forty-six typically developing children participated in the study. There were fifteen 3.5-year-olds, sixteen 5.5-year-olds, and fifteen 8-year-olds. Girls and boys were represented evenly across the three age groups. Seven children in the youngest age group, however, did not complete testing, either because of refusal, or because they could not complete the identified task. Thus the final sample consisted of 39 children (21 girls and 18 boys).

The first author (L.C.), an experienced pediatric physical therapist, conducted all testing with an assistant. Four assistants participated in data collection. All were physical therapists with at least 3 years of clinical experience. Before testing began on the SOT and the P-CTSIB, the examiner recorded an average of two measurements of height (cm), weight (kg), foot length (cm), and head circumference (cm) for each child.

The order of administration of the SOT and P-CTSIB was randomly assigned. If the SOT was completed first, the examiner was kept unaware of the SOT scores. If the P-CTSIB was done first there would be no scoring bias since SOT scores are computer generated. Testing took approximately 1 hour for each child, including a 15-minute break between the two tests.

The SOT was performed using the Smart EquiTest System (NeuroCom International Inc., Clackamas, OR, USA). The examiner calibrated the posturography equipment each day before testing began. The examiner introduced the testing protocol for the SOT to the children as the "Statue Game" (Gabriel & Mu, 2002). Children were asked "to stand as still as possible as if you were a statue." The children were also instructed to look at a picture 1.5 feet away. The children stood in bare feet with their arms relaxed by their sides. For safety, the children wore a harness which is part of the Smart EquiTest system (Figure 3-3). The examiner stood close behind each child during testing but did not touch the child. In this position the examiner could provide assurance to the children during testing and also ensured that the children kept their eyes closed during Conditions 2 and 5. Each child performed three trials of 20 seconds for each of the six sensory conditions in succession. The six conditions were completed sequentially from Condition 1 to Condition 6 taking an average of 20 minutes to complete. The children received a sticker in between conditions to keep them interested and motivated.

The computer produces an outcome measurement called the *Equilibrium Score* as a measure of anterior-posterior postural sway. The Equilibrium Score is a percentage of the sway angle relative to the theoretical limits of stability. Sway angle refers to the angular distance between a line projecting from the centre of the subject's base of support to the subject's the centre of gravity and, and a second line projecting directly vertical from the centre of the subject's base of support (Rine, Rubish, & Feeney, 1998). The theoretical limits of stability refers to the maximum possible sway angle of 12.5 degrees, determined to be the point at which the centre of gravity falls at the outer perimeter of the base of support (NeuroCom International Inc., 2001). The Equilibrium Score is scaled so that a higher percentage score indicates less sway (Rine et al., 1998). The highest possible score is 100, indicating no sway. The lowest possible score is 0, which indicates postural sway to the theoretical limit or a stopped trial (NeuroCom International Inc., 2001). An Equilibrium Score is obtained for each of the three trials under each of the six conditions.

The examiner introduced the P-CTSIB testing protocol to the children as the "The Snowman Game." They were instructed to "stand as still as possible as if you were frozen like a snowman." They were tested in bare feet with their feet together and their hands on their hips. The assistant sat on a stool close behind the child but did not touch the child. Each child performed two trials of 30 seconds for each of the six sensory conditions in succession. All six conditions were completed sequentially from Condition 1 to Condition 6 during the same session, requiring approximately 20 to 25 minutes. The children were given a sticker in between conditions.

The P-CTSIB is usually administered with the child's feet in two positions: (a) feet together with medial malleoli touching, and (b) heel-toe with the preferred foot behind the non-preferred foot with the toes touching the heel (Richardson, Atwater, Crowe, & Deitz, 1992). For this study, the feet together position only was used for three reasons. First, in a study examining the P-CTSIB in children 4- and 5-year-olds, researchers concluded that the heel-toe position could not be used diagnostically in this age group due to its level of difficulty (Richardson et al., 1992). Second, low test-retest reliabilities and high magnitudes of difference between test and retest scores contributed to researchers not recommending the heel-toe position for clinical use (Westcott, Crowe, Deitz, & Richardson, 1994). Third, the heel-toe position examines a child's lateral sway, as opposed to anterior-posterior sway in the feet together position. We examined the amount of anterior-posterior sway only as this is the type of sway that is measured in the SOT.

The examiner measured postural sway using a backdrop with lines radiating in one-degree increments from a central axis at the floor. The lines radiated to a maximum of 20 degrees of sway in each direction. The child was positioned beside the backdrop so their medial malleoli were lined up to the vertical line at 0 degrees (Figure 3-4). The examiner recorded the total anterior-posterior sway by using the child's nose or a vertical pointer on the paper dome as a reference point (Crowe et al., 1990). The children were instructed to look at a picture approximately 3 feet away. This assisted the children to visually fixate on an object to maintain their head in the same position and improve the accuracy of the postural sway measurement. The assistant timed the duration of standing balance using a stopwatch. Timing began when the child was in position and the assistant let go of the child. Timing stopped when the child maintained the position for 30 seconds or when a postural adjustment was made. A postural adjustment is defined as "removing hands from hips, moving one or both feet from the original position, opening eyes during the eyes-closed condition, or requiring assistance from the examiner to prevent a fall" (Richardson et al., 1992, p. 796).

The examiner measured the amount of sway, and recorded sway and duration scores on a data sheet (Appendix A). The assistant gave the child directions, positioned the child, guarded against falls, and timed the duration of standing balance. She also ensured the eyes were kept closed during Conditions 2 and 5. For each condition, we chose the best score of the two trials based on previous test administration guidelines (Westcott et al., 1994). The best trial is defined as the trial with the longest duration, or if both trials have equal duration, the trial with the least amount of postural sway. Because we used the best score of two trials for the P-CTSIB, we also used the best Equilibrium score of the three trials for each condition for the SOT.

Statistical Analysis

SPSS 12.0 for Windows (SPSS Inc., Chicago, IL, USA) was used for all statistical analysis. Pearson product-moment correlation coefficients were generated to evaluate the concurrent validity of the P-CTSIB and the SOT. To determine whether there were significant differences between the correlation coefficients of each condition, we constructed 95% confidence intervals around each correlation coefficient (Lane, 2003).

Differences in the SOT Equilibrium scores for each of the six sensory conditions across the three age groups were analyzed using a series of one-way ANOVA's (6 in total) with a Bonferroni correction of $p < .01$ and post-hoc analysis (Tukey's Honestly Significant Difference). Differences in the P-CTSIB postural sway scores were analyzed using the same statistical methods as the SOT Equilibrium scores.

To evaluate the effect of anthropometric measures on test scores, we performed a series of step-wise regression analyses for each score obtained on the P-CTSIB and the SOT (12 in total). Ratio scores (height / head circumference, height / weight, height / foot length, foot length / head circumference) rather than absolute anthropometric measures were used to avoid confounding anthropometric measures with age. We chose the anthropometric variables for each ratio score based on hypotheses of which paired variables may influence postural control. The variables entered into each regression were the ratio scores and the comparative condition score from the other test.

Results

Thirty-nine children (mean age = 6.3 years, *SD* = 1.8) completed all six conditions of the SOT and the P-CTSIB, eight 3.5-year-olds (mean age = 3.7 years, *SD* = 0.1, 6 girls and 2 boys), sixteen 5.5-year-olds (mean age = 5.7 years, *SD* = 0.2, 8 girls and 8 boys), and fifteen 8-year-olds (mean age = 8.3 years, *SD* = 0.2, 7 girls and 8 boys). The SOT and P-CTSIB scores (mean and *SD*) for each condition and each age group are listed in Tables 3-1 and 3-2.

Correlation coefficients between the P-CTSIB scores and the SOT scores for each of the six conditions are provided in Table 3-3. Correlation coefficients ranged from -.11 (Condition 5) to -.69 (Condition 1); these values represent poor to moderate relationships between the P-CTSIB and the SOT (Portney & Watkins, 2000). The 95% confidence intervals around the correlation coefficients for all six conditions overlapped which indicated that measurement variability could account for the differing absolute values (Table 3-3).

The one-way ANOVAs revealed significant differences among the three age groups in Conditions 1, 2, 3, and 4 of both the P-CTSIB and SOT. Examination of pair-wise differences revealed significant differences between at least two age groups for all conditions on both tests except Conditions 5 and 6 (Tables 3-1 and 3-2).

In the step-wise regression analyses for the SOT Equilibrium Scores only the height / head circumference ratio entered the equation for conditions 2, 3, 4 and 6. It accounted for 47% of the score variance in Condition 2, 24% of the variance in Condition 3, 25% of the variance in Condition 4, and 13% of the variance in the score in Condition 6. In condition 1, height / head circumference ratios accounted for 60% of the score variance. The P-CTSIB score was entered in the second step which accounted for another 10% of the score variance on the SOT. For Condition 5, no predictor variables were entered due to low correlations for each of the variables with the SOT Equilibrium Score.

The step-wise regression analyses for predicting the P-CTSIB postural sway scores revealed that the height / head circumference ratio accounted for the greatest variance of the scores in Condition 2 (39%), Condition 3 (42%), Condition 4 (18%), and Condition 6 (21%). In Condition 1, the SOT Equilibrium Score accounted for 48% of the variance in the score. The model entered only one predictor variable for the score in each condition except in Conditions 5. In Condition 5, no predictor variables were entered due to low correlations for each of the variables with the P-CTSIB scores.

Discussion

The main objective of this study was to examine the concurrent validity of scores obtained by typically developing children on the P-CTSIB and the SOT. The results of this study suggest that the relationship between the P-CTSIB postural sway scores and the SOT Equilibrium scores ranges from poor to moderate for the six sensory conditions. These results do not support the assumption that the P-CTSIB can be used as a proxy measure to the SOT.

Secondary objectives included examining differences in mean scores on the P-CTSIB and SOT among the three age groups, and evaluating the influence of anthropometric factors on the scores obtained on the two tests. The results suggest that the differences in scores across the three age groups are not as clear as previously assumed (Shumway-Cook & Woollacott, 2001; Westcott et al., 1997). Analyses of anthropometric factors reveal that the height to head circumference ratio may be more predictive of the scores on the P-CTSIB or the SOT than the comparative sensory condition score of the other test. This also questions the utility of using the P-CTSIB as a reliable method to test postural control in children.

Concurrent Validity

The poor to moderate concurrent validity of the P-CTSIB and the SOT appears to be influenced by the differences in the physical attributes of the two tests. Psychometric characteristics of the tests, specifically the reliability of both tests, and the small range of values obtained on the P-CTSIB, may also have influenced the magnitude of the relationships between the two tests. The physical attributes and the psychometric issues are discussed separately.

Physical attributes. Overall, the absolute magnitude of the correlation coefficients between conditions on the two tests decreased as conditions became theoretically more challenging. These correlation coefficients are likely influenced by the physical attributes of the comparative conditions on the SOT and the P-CTSIB. The strongest relationships between the P-CTSIB and the SOT were in Conditions 1 (-.69) and 2 (-.60). Both of these conditions on the P-CTSIB and the SOT use a fixed surface and involve having eyes open (Condition 1) and closed (Condition 2). No sensory conflict is presented in these two conditions.

Conditions 3, 4, 5, and 6 require the use of additional materials to create sensory conditions that present a person with sensory conflict. The P-CTSIB uses a piece of medium density T-foam and a paper dome to mimic conditions on the SOT created by the Smart EquiTest system. The simple materials used in the P-CTSIB produced different responses to the comparable test condition using the SOT. In particular, the foam used in Conditions 4, 5, and 6 of the P-CTSIB seemed to present a much less challenging balance task for the children than the moveable forceplates used for the same conditions on the SOT. The foam did not appear to compress very much under the weight of the children. It provided the children with a relatively stable, non-moving surface that was very different than the forceplates that moved in a 1:1 ratio in response to their postural sway. The difference in these two surface supports likely created dissimilar postural sway responses.

These results are contrary to the findings of Allum and colleagues (2002) and Weber and Cass (1993) who reported that the foam support surface presented a more difficult balance task for adults than the comparative conditions of the SOT using the EquiTest system (NeuroCom Inc., Clackamas, OR, USA). Their results may differ from our results for two reasons: (a) the foam support used in these two studies was much thicker (8 inches and 4 to 6 inches) than our 3-inch foam support, and (b) adults are heavier than children. As a result of both of these factors, adults in these studies probably were able to compress the foam to a higher degree than the children in our study and thus produce a more unstable support. Allum and colleagues (2002) noted that the foam support tested trunk sway in multiple directions, whereas the moveable forceplates tested trunk sway in only the anterior-posterior directions. These researchers found the two support surfaces appeared to be testing different directional aspects of postural control and they suggested that these two support surfaces are not comparable.

In our study, the differences in the support surfaces may also explain our results. Theoretically, as the forceplates move in a 1:1 ratio in response to a person's postural sway, somatosensory inputs would indicate no body movement in relation to the support surface. The foam surface, on the other hand, is more likely to provide a person with some somatosensory input indicating body movement in relation to the support surface. Subsequently, the conditions involving the foam surface may only be providing a person with *decreased* somatosensory information instead of *orientationally inaccurate* somatosensory information. Therefore, in Conditions 4, 5, and 6 of the P-CTSIB, somatosensory information may not truly conflict with visual or vestibular information. This situation may make the task of resolving sensory conflict easier to reconcile.

The discrepancy in the physical attributes between the two tests may also explain the differences found when ranking conditions from easiest (causing the least amount of postural sway) to most difficult (causing the greatest amount of postural sway). When the scores on the P-CTSIB and the SOT are ranked according to difficulty, two distinct patterns emerge. The P-CTSIB conditions ranked from easiest to most difficult are Conditions 1, 4, 2, 5, 3, and 6. The SOT conditions ranked from easiest to most difficult are Condition 1, 3, 2, 4, 6, and 5. The rank order of the P-CTSIB conditions appears to be most influenced by the change in visual input. The most difficult conditions on the P-CTSIB involve wearing the visual conflict dome (Conditions 3, 6) and having eyes closed (Conditions 2 and 5). On the other hand, the most difficult conditions on the SOT appear to be the conditions that involve the movable forceplates (Conditions 4, 5, 6). The change in the support surface appears to be the key variable influencing the rank order of the SOT conditions. This provides further support that the movable forceplates present a much greater challenge to postural control in the SOT then the foam surface in the P-CTSIB.

Psychometric issues. Measurement factors that may have influenced the concurrent validity between the two tests include the low variability of scores on the P-CTSIB and the reliability of both the P-CTSIB and the SOT. The range of P-CTSIB scores for all the participants was 4 degrees for Conditions 1, 2, 4, and 6; 5 degrees for Condition 3; and 6 degrees for Condition 5. This indicates the postural sway of 3.5-, 5.5-, and 8-year-olds as measured by the P-CTSIB only differed at most by 6 degrees. On the other hand, the range of SOT Equilibrium Scores varied from a low of 16% (Condition 2) to a high of 74% (Condition 6). This does not include scores of 0 which indicated a fall or a stopped trial. The degree of relationship between the two tests will be limited by the attenuation of the range of P-CTSIB scores.

The reliability of both measures has also not been well established. Two studies have examined the reliability of the SOT in typically developing children (Liao, Mao, & Hwang, 2001; Rine et al., 1998). Rine and colleagues examined the reliability of scores of 23 children (3 – 7.5 years) on the SOT obtained on two successive trials in each of the sensory conditions. Scores were stable across trials with Chronbach's alpha ranging from .65 (Condition 6) to .95 (Conditions 2 and 4), suggesting moderate to excellent reliability in the same session.

Liao and colleagues tested same session reliability and test-retest reliability of SOT scores. Same session reliability was tested with 16 children ranging from 6 years 9 months to 12 years 2 months of age. The intraclass correlation coefficients (ICCs) for the six sensory conditions ranged from -.1 (Condition 5) to .62 (Condition 2), indicating poor to moderate reliability. Test-retest reliability (1 week apart) was tested in 14 children ranging from 6 years 9 months to 13 years 2 months. ICCs ranged from .25 (Condition 1) to .84 (Condition 3), indicating poor to good reliability. The results of these two studies suggest that reliability of the SOT is moderate to good at best, and is influenced by the condition that is tested.

Reliability of the P-CTSIB for typically developing children is reported in two articles. Crowe and colleagues (1990) evaluated the inter-rater reliability of P-CTSIB scores obtained by two examiners simultaneously assessing 24 children ages 4 to 9 years. They reported Spearman rank order correlation coefficients ranging from .69 (Condition 3) to .90 (Condition 5), indicating moderate to excellent reliability for the measurement of sway. Westcott and colleagues (1994) also used a sample of 24 children in the same age range to examine the test-retest reliability of the P-CTSIB. The same examiner tested each child on the P-CTSIB on two different occasions, 1 week apart. Spearman's rank order correlation coefficients for test-retest reliability for sway measurements of the P-CTSIB feet-together position ranged from .37 (Condition 2) to .70 (Condition 5), indicating poor to moderate reliability.

Based on the results from these four studies, it is difficult to establish the reliability of the two measures with great confidence. The reliability results suggest that there is variability in repeated postural sway scores on both measures and that this variability is influenced by the test condition. Poor reliability of the SOT and the P-CTSIB will influence the degree of concurrent validity between the two tests.

It is important to consider, however, that variability of scores seen in a measurement tool may not reflect solely measurement error. The variability seen in the SOT and P-CTSIB scores in all sensory conditions could also represent natural variability inherent in the postural control of typically developing children. Brouwer and colleagues (1997) examined the reliability of static and dynamic measures of postural control using computerized dynamic posturography with 70 healthy young adults aged 20 to 32 years. These researchers suggested that healthy individuals are able to sway comfortably within a large sway envelope without losing their balance. Subsequently their response patterns were highly variable. They also determined that postural sway during quiet stance was variable both within and across subjects, and that this variability increased as increased challenge was presented to the postural control system. Our study illustrates that scores on the P-CTSIB and the SOT became more variable from Condition 1 to Condition 6. Variability in postural sway may be an inherent characteristic of postural control, especially when the conditions become more challenging. This explains in part why the correlation coefficients decreased with increasing difficulty of the sensory conditions.

Both measurement reliability and natural variability in children's performance may influence the variability of scores. Because of this, it may be difficult to obtain consistent postural sway scores in individual children. This creates the possibility that a child's performance on the P-CTSIB and the SOT at different times would result in different postural sway scores. This inconsistency in scores will make it more difficult to discover if there is a relationship between the SOT and the P-CTSIB. The degree of concurrent validity between the two tests can only be determined if the measures themselves are reliable. Without reliability, one cannot establish validity (Ary, Jacobs, & Razavieh, 1996). Clearly, further reliability testing is necessary for both tests before we can truly establish the level of concurrent validity between the two tests.

Differences in the Three Age Groups

Examination of mean scores between the three age groups for each of the six conditions revealed that differences among the age groups were not as distinct as suggested in the literature (Shumway-Cook & Woollacott, 2001; Westcott et al., 1997). Shumway-Cook and Woollacott (1985) originally hypothesized that a critical transition period occurs between the ages of 4 and 6 years. This hypothesis was largely based on observing automatic postural muscle responses to horizontal platform translations in children between 15 months and 10 years of age. They found that children 4 to 6 years of age generally had slower and more variable muscle responses as recorded by electromyography (EMG) than younger children aged 15 to 31 months, or older children aged 7 to 10 years. They suggested that the apparent regression in muscle response was indicative of a shift from visual to somatosensory dominance in postural control and the emergence of sensory organization ability. Many studies that examined developmental changes in postural control frequently refer to this critical transition period (Deitz, Richardson, Atwater, Crowe, & Odiorne, 1991; Foudriat et al., 1993; Richardson et al., 1992; Rine et al., 1998; Shumway-Cook & Woollacott, 2001; Sugden, 1992; Westcott & Burtner, 2004; Woollacott et al., 1987; Woollacott et al., 1989).

Based on this literature, we chose children who were 3, 5, and 8 years old for our study to determine if there were significant differences among children who had not yet entered the transition period, children who were in the middle of the transition period, and children who had matured beyond the transition period. We expected to find clear differences between the age groups, particularly in conditions that presented the children with sensory conflict (Conditions 3, 4, 5, 6). While 3.5-year-olds and 8-year-olds generally exhibited significant differences in SOT and P-CTSIB scores, there were few significant differences in the scores of the other age groups, particularly between the two youngest age groups.

Analysis of significant differences among the age groups yielded different findings for the P-CTSIB versus the SOT scores. There was agreement only in Conditions 5 and 6 of both tests where no significant differences were found among the three age groups (Tables 1 and 2). This result was not surprising based on our analysis of the concurrent validity between the two tests. Due to the measurement concerns with the P-CTSIB, namely the attenuation of scores, low reliability, and indeterminate sensory conflict created using the T-foam; we focused on the SOT scores to examine significant differences between the different age groups.

It appears that when children have all three sensory systems providing information that is in agreement, there are clear age differences (SOT Condition 1). However, when one or more sensory systems provide orientationally inaccurate or absent sensory information, the differences between the three age groups are no longer distinct.

In sensory conditions where children only have vestibular input on which to rely (Conditions 5 and 6), there are no significant differences in the three age groups. The lack of significant differences is influenced by the large variability of scores within each age group, demonstrated by the standard deviations obtained in each age group. The standard deviation on Conditions 5 and 6 is greater than all of the other conditions among 3.5-, 5.5- and 8-year-olds. This illustrates that there is a wide range of abilities among and within the three age groups in these two conditions. Our results reveal that in Conditions 5 and 6, some 3.5-year-olds scored better than some 8-year-olds.

The findings in the remaining conditions of the SOT (Conditions 2, 3, and 4) are more ambiguous. All three conditions revealed significant differences between 3.5- and 8-year-olds, but no significant differences between 3.5- and 5.5-year-olds. Other researchers that examined children of this age using the SOT also did not find significant differences between 3- and 5-year-olds in these conditions (Foudriat et al., 1993; Hirabayashi & Iwasaki, 1995; Rine et al., 1998). This suggests that the postural control of 3- and 5-year-olds may be very similar under these sensory conditions.

Possible explanations for these findings are that 1) the transition period starts before the age of 4 years, 2) there is no transition period, or 3) there are factors other than age that contribute to differences in postural control in children.

The lack of significant differences between 3.5- and 5.5-year-olds in Conditions 2, 3, and 4 may indicate that the transition period begins before the age of 4 years. Foudriat and colleagues, based on SOT results in their study (1993), suggested that sensory organization ability may develop as early as 3 years old and that the transition period may be from 3 to 6 years old. Studies by Woollacott et al. (1987) and Foster et al.

(1996), based on EMG results, indicated that the transition phase might occur as early as 2 to 3 years old. It is possible that our youngest age group of children at 3.5 years old may have already entered the hypothesized transition period, making their scores similar to the 5.5-year-olds. We were not able to test children younger than 3.5 years old using the SOT thus making it difficult to compare 5.5-year-olds to an even younger age group. In addition, seven of the fifteen 3.5-year-old children either could not complete testing or refused to participate in testing. It is possible that these children may have had more immature postural control than the children who successfully completed the testing. The eight 3.5-year-olds who completed the testing may have been the most developmentally mature children in this age group and may not be representative of typical 3.5-year-olds. This would also contribute to the lack of significant differences between the 3.5- and 5.5-year-olds in our study.

The hypothesis of a critical transition period between the ages of 4 and 6 years in the development of postural control is mentioned often in developmental literature (Bradley, 1994; Shumway-Cook & Woollacott, 2001; Woollacott et al., 1989). Despite other research indicating that the transition period may start earlier (Foudriat et al., 1993; Woollacott et al., 1987) or that differences between these age groups were not found (Foudriat et al., 1993; Hirabayashi & Iwasaki, 1995; Rine et al., 1998), the developmental literature continues to make reference to this transition period between 4 and 6 years. It is interesting to note that this hypothesis is based largely on the results of two studies which primarily used EMG recordings as the outcome measure (Shumway-Cook & Woollacott, 1985; Woollacott et al., 1987). In the first study, Shumway-Cook and Woollacott (1985) used EMG recordings to measure automatic postural muscle responses to a horizontal platform perturbation. The EMGs indicated that 4- to 6-year-olds had more variable and latent postural muscle responses compared to 15- to 31-month-olds and 7- to 10-year-olds. The researchers in the second study (Woollacott et al., 1987) also used surface EMGs to illustrate that 4- to 6-year-olds had decreased and more variable neck responses to a horizontal platform perturbation as compared to 2- to 3-year-olds or adults. EMG recordings, however, are a measure of muscle activation and not a measure of postural sway. The relationship between EMG recordings and postural sway is not clear. It may be incorrect to assume that differences between the age groups based on EMG recordings of muscle responses to postural perturbations may hold true when using the SOT. It is also difficult to have great confidence in their results because there were less than 8 children in each of the age groups. For these reasons, it is possible that the hypothesis of a transition period within this narrow age range may have been overemphasized in the literature. More examination and evaluation of this hypothesis is clearly needed.

The absence of consistent postural sway responses and large variability within and across age groups lead us to speculate whether there are factors other than age that contribute to differences in postural control in children. Some researchers have wondered whether the transition period may be related to a growth spurt occurring during these ages that results in biomechanical changes in the body proportions of children (Shumway-Cook & Woollacott, 2001; Woollacott et al., 1989).

Anthropometric Factors

The results from the step-wise regression analysis indicate that the height / head circumference ratio was more predictive of SOT scores in Conditions 1, 2, 3, and 4; and of P-CTSIB scores in Conditions 2, 3, 4, and 6 than any other variables, including the children's scores on the other test. These results suggest that postural control became worse as head circumference increased relative to height. One explanation may be the change in the location of the centre of gravity. A person with a proportionally large head compared to their height has a relatively higher centre of gravity (COG) than a person with a proportionally small head size compared to their height. A relatively higher COG is associated with a faster rate of postural sway (Forssberg & Nashner, 1982; Shumway-Cook & Woollacott, 2001). This increased rate of postural sway will increase the challenge of maintaining postural control.

In our study, the P-CTSIB scores did not factor into the stepwise regression to predict SOT scores except in Condition 1. In this condition, the P-CTSIB score was entered as the second step after the height / head circumference ratio to account for 10% of the variance in the SOT score. The SOT scores also did not factor into the stepwise regression to predict P-CTSIB scores except in Condition 1. The SOT score for Condition 1 accounted for 48% of the variance in the P-CTSIB score and was the only variable entered into the model for this condition. These findings provide further evidence that, except in Condition 1, the scores of the two measures are not strongly related.

These findings suggest that therapists need to consider anthropometric factors in addition to developmental age norms when assessing postural control in children. This is an important concept in ecological task analysis as presented by Burton and Davis (Burton & Davis, 1996; Davis & Burton, 1991). Burton and Davis argue that instead of focusing on a child's age and using normative scores to evaluate a child's performance in a particular task, one should examine the child's performance using performer-scaled or intrinsic dimensionless ratio measures. For example, Burton, Greer, and Wiese- Bjornstal

(1993) discovered that the ball / hand width ratio was a critical factor in determining whether a person used a one- to two-hand grasp to hold a ball.

Based on the step-wise regression analysis in our study, it appears that the height / head circumference ratio may be a critical factor in the SOT and P-CTSIB scores. There is a positive correlation between the height / head circumference ratio and the SOT scores. This illustrates that as the head circumference increases relative to height, SOT scores will decrease indicating there is more postural sway. The P-CTSIB scores, on the other hand, have a negative correlation with the height / head circumference ratio. This illustrates that as the head circumference increases relative to height, P-CTSIB scores will increase which also indicates there is more postural sway. Head circumference and height likely determine the location of a person's centre of gravity. This may be one of the reasons why children have decreased postural control compared to adults because children's head sizes are proportionally larger than adults' head sizes relative to their height. This supports Habib and Westcott's (1998) hypothesis that early maturing children who are taller might have better scores on these tests than shorter children of the same age.

A child's postural control response in certain sensory conditions may depend more on when a child reaches certain body dimensions or proportions versus reaching a particular age. Therapists may need to consider certain anthropometric factors instead of age norms when evaluating postural control in children. Further research in this area to explore this theory could include examining postural control of children of different ages who have similar body proportions and head circumference to height ratios.

The findings from this study are limited to typically developing children in the age groups studied. They cannot be extrapolated to children with postural control difficulties or to children with specific diagnoses. In addition, concurrent validity of the P-CTSIB and the SOT only pertain to measures of anterior-posterior postural sway. Other measures of the P-CTSIB used by the developers of the test, such as duration and combined scores were not evaluated. Postural control in this study was also only assessed in a static steady state standing position. Reactive postural responses to platform perturbations or anticipatory postural responses were not investigated. Children also rely on postural control in a variety of functional activities. We do not know the relationship of the SOT and P-CTSIB to function in typically developing children.

Conclusion

Overall, this study provides evidence that the P-CTSIB cannot be used as a proxy measure for SOT. We can have reasonable confidence that P-CTSIB scores in Conditions 1 and 2 will be similar to SOT scores. P-CTSIB scores in Conditions 3, 4, 5, 6, however, must be interpreted with caution. The attenuation of postural sway scores observed in the P-CTSIB data does not allow it to capture the range of scores that were observed in the SOT scores. Further testing of the validity and reliability of the P-CTSIB is needed before it can be used clinically with confidence.

The large variance of scores observed in the SOT, especially in Conditions 5 and 6, may not only be due to measurement reliability but also natural variability in children's performance in different sensory conditions. Further studies examining natural variability in the postural control of children are warranted. This factor may influence the methods or outcome measures that therapists use to evaluate postural control.

This research study illustrates that postural control is influenced by many factors including environmental conditions and anthropometric characteristics. This supports the need for physical therapists to consider a variety of systems that may contribute to postural control dysfunction. It is important for therapists to determine what components of postural control are being tested using different outcome measures or clinical tests. A more systematic analysis of postural control may lead to better understanding of which factors may be involved in postural control dysfunction.

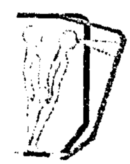
Condition	Diagram	Description	Orientationally Accurate Sensory Systems	Absent or Inaccurate Sensory Systems
Condition 1		Eyes Open Fixed Surface	Vision Somatosensory Vestibular	
Condition 2		Eyes Closed Fixed Surface	Somatosensory Vestibular	Absent Vision
Condition 3		Sway-Referenced Vision Fixed Surface	Somatosensory Vestibular	Inaccurate Vision
Condition 4		Eyes Open Sway-Referenced Surface	Vision Vestibular	Inaccurate Somatosensory
Condition 5		Eyes Closed Sway-Referenced Surface	Vestibular	Absent Vision Inaccurate Somatosensory
Condition 6		Sway-Referenced Vision Sway-Referenced Surface	Vestibular	Inaccurate Vision Inaccurate Somatosensory

Figure 3-1. Six sensory conditions of the Sensory Organization Test (SOT)

Note. From NeuroCom International, Inc. (1999). *Sensory Organization Test (SOT): sensory analysis* [Brochure]. Clackamas, OR: NeuroCom International, Inc. Copyright 1999 by NeuroCom International, Inc. Adapted with permission.

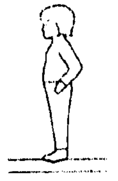
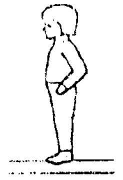
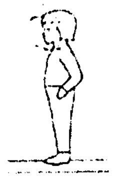
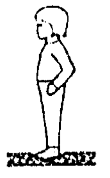
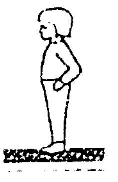
Condition	Diagram	Description	Orientationally Accurate Sensory Systems	Absent or Inaccurate Sensory Systems
Condition 1		Eyes Open Flat Surface	Vision Somatosensory Vestibular	
Condition 2		Eyes Closed Flat Surface	Somatosensory Vestibular	Absent Vision
Condition 3		Visual-Conflict Dome Flat Surface	Somatosensory Vestibular	Inaccurate Vision
Condition 4		Eyes Open Foam Surface	Vision Vestibular	Inaccurate Somatosensory
Condition 5		Eyes Closed Foam Surface	Vestibular	Absent Vision Inaccurate Somatosensory
Condition 6		Visual-Conflict Dome Foam Surface	Vestibular	Inaccurate Vision Inaccurate Somatosensory

Figure 3-2. Six sensory conditions of the Pediatric Clinical Test of Sensory Interaction for Balance (P-CTSIB)

Note. From "Interrater reliability of the Pediatric Clinical Test of Sensory Interaction for Balance," by T. K. Crowe, J. C. Deitz, P. K. Richardson, and S. W. Atwater, 1990, *Physical and Occupational Therapy in Pediatrics, 10*(4), p. 10. Copyright 1991 by Haworth Press, Inc. Adapted with permission.

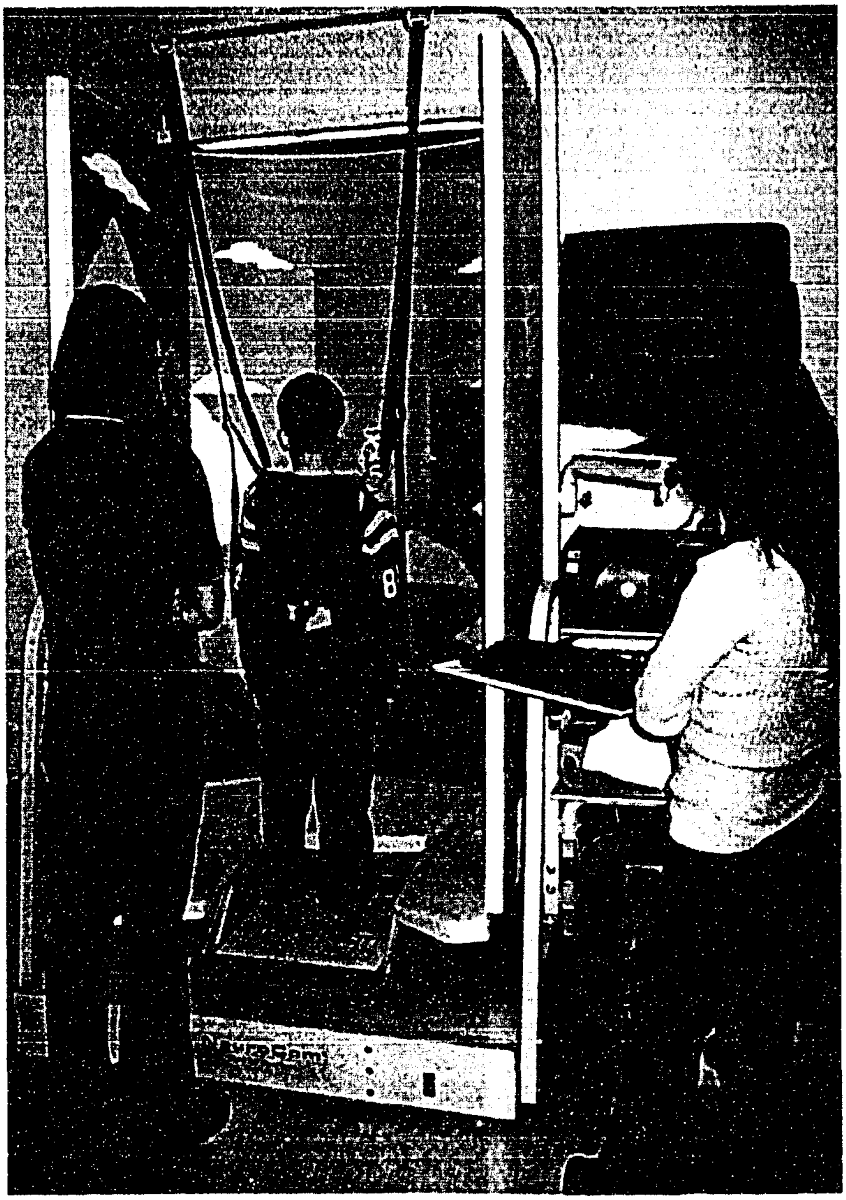


Figure 3-3. Position of child wearing harness during SOT testing

Figure 3-4. Position of child wearing safety belt during P-CTSIB testing

Table 3-1

SOT Descriptive Statistics and Significant Age Group Differences

Condition	Age group (years)	Mean	SD	Min.	Max.	Range	Significant Differences*
SOT Condition 1	3.5	83.13	5.49	75	89	14	3.5 vs. 5.5
	5.5	88.88	2.16	85	92	7	3.5 vs. 8
	8	93.13	1.69	90	96	6	5.5 vs. 8
SOT Condition 2	3.5	81.75	3.99	77	88	11	
	5.5	86.19	4.48	78	93	15	3.5 vs. 8
	8	90.27	1.44	88	93	5	5.5 vs. 8
SOT Condition 3	3.5	82.13	7.12	71	90	19	
	5.5	88.06	5.18	77	94	17	3.5 vs. 8
	8	90.13	3.76	83	95	12	
SOT Condition 4	3.5	65.63	7.48	55	74	19	
	5.5	68.75	11.36	40	83	43	3.5 vs. 8
	8	82.20	7.38	60	93	33	5.5 vs. 8
SOT Condition 5	3.5	48.38	22.49	0	73	73	
	5.5	44.88	18.87	0	73	73	
	8	58.07	14.35	37	77	40	
SOT Condition 6	3.5	49.50	21.57	0	68	68	
	5.5	56.00	15.80	12	78	66	
	8	68.87	11.43	45	86	41	

* Tukey HSD at $p < 0.01$

Table 3-2

P-CTSIB Descriptive Statistics and Significant Age Group Differences

Condition	Age group (years)	Mean	SD	Min.	Max.	Range	Significant Differences*
PCTSIB Condition 1	3.5	3.25	.89	2	5	3	
	5.5	2.44	.51	2	3	1	3.5 vs.8
	8	1.73	.80	1	3	2	
PCTSIB Condition 2	3.5	4.25	.71	3	5	2	3.5 vs. 5.5
	5.5	3.06	.44	2	4	2	3.5 vs. 8
	8	2.60	.74	1	4	3	
PCTSIB Condition 3	3.5	5.13	1.13	4	7	3	
	5.5	4.06	.68	3	5	2	3.5 vs.8
	8	3.13	.74	2	4	2	5.5 vs. 8
PCTSIB Condition 4	3.5	3.13	.99	2	5	3	
	5.5	2.38	.50	2	3	1	3.5 vs. 8
	8	2.00	.54	1	3	2	
PCTSIB Condition 5	3.5	3.88	.99	2	5	3	
	5.5	3.88	1.31	2	8	6	
	8	3.80	.94	3	6	3	
PCTSIB Condition 6	3.5	5.13	.84	4	6	2	
	5.5	4.75	1.12	3	7	4	
	8	3.87	1.06	3	6	3	

* Tukey HSD at $p < 0.01$

Table 3-3

Pearson Product-Moment Correlation Coefficients and 95% Confidence Intervals of the SOT and the P-CTSIB

		95% Confidence Interval	
		Lower Bound	Upper Bound
Condition 1	-.69	- .86	-.40
Condition 2	-.60	-.77	-.35
Condition 3	-.44	-.67	-.14
Condition 4	-.32	-.58	.00
Condition 5	-.11	-.42	.22
Condition 6	-.23	-.51	.09

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CHAPTER 4

TEST-RETEST RELIABILITY OF THE P-CTSIB

Introduction

In the last two decades there has been an emphasis in rehabilitation to develop and use reliable, valid and standardized measures (Huijbregts, Myers, Kay, & Gavin, 2002; Law, 2003). Outcome measurement is becoming increasingly important in a health care environment that emphasizes evidence-based practice and accountability for limited resources (Beattie, 2001). In the clinical setting, outcome measures are often used to identify problem areas, evaluate the effectiveness of treatment, and to provide quantitative documentation of change in a child's status over time.

Pediatric physical therapists frequently evaluate postural control of children. The assessment and evaluation of postural control is challenging because it is influenced by the interaction of many systems within the child, task, and environment (Shumway-Cook & Woollacott, 2001). Within the child, the biomechanical, motor, and sensory systems are considered important systems that influence postural control (Horak, 1987; Nashner, 1997b; Westcott, Lowes, & Richardson, 1997). Many tests and outcome measures have been developed to evaluate the biomechanical and motor aspects of postural control but few measure sensory system influences on postural control (Westcott et al., 1997). Two measures that have been developed for this purpose are the Sensory Organization Test (SOT) (Forssberg & Nashner, 1982; Nashner, 1982) and the Pediatric Clinical Test of Sensory Interaction for Balance (P-CTSIB) (Crowe, Deitz, Richardson, & Atwater, 1990; Shumway-Cook & Horak, 1986).

The SOT has become the "gold standard" for the objective measurement of the visual, somatosensory, and vestibular inputs that affect postural control (El-Kashlan, Shepard, Asher, Smith-Wheelock, & Telian, 1998; Gabriel & Mu, 2002; Keshner, 1994). The SOT systematically measures the influence of the three sensory systems by measuring the amount of postural sway under six sensory conditions (Figure 4-1). These six conditions represent combinations of three visual (eyes open, eyes closed, or altered using a sway-referenced visual surround) and two support surface variables (flat surface or a sway-referenced surface). Sway-referencing refers to having the visual surround or support surface move in a 1:1 ratio according to the subject's postural sway (Nashner, 1997a). The six sensory conditions include (a) eyes open, flat surface (Condition 1); (b) eyes closed, flat surface (Condition 2); (c) sway-referenced visual surround, flat surface (Condition 3); (d) eyes open, sway-referenced surface (Condition 4); (e) eyes closed, sway-referenced surface (Condition 5); and (f) sway-referenced visual surround, sway-referenced surface (Condition 6). The SOT also tests a person's sensory organization ability in the conditions that present with conflicting sensory information (Conditions 3, 4, 5, and 6).

For an outcome measure to be considered useful and effective for therapists, it not only has to demonstrate sound psychometric properties but also needs to have clinical utility. Considerations around the use of an outcome measure in a clinical setting include its availability, cost, training requirements, and ease of administration, scoring, and interpretation (Law, 2003). The SOT is generally not useful for most pediatric physical therapists because it requires the use of specialized and expensive dynamic posturography equipment that is primarily available in research labs or large rehabilitation centres.

The Pediatric Clinical Test of Sensory Interaction for Balance (P-CTSIB) is a clinical measure of postural control that was developed based on the SOT (Crowe et al., 1990; Shumway-Cook & Horak, 1986). The P-CTSIB is used to measure postural sway under similar sensory conditions as the SOT (Figure 4-2). It can be easily administered by physical therapists in a variety of settings and requires minimal equipment. The P-CTSIB offers clinicians a method to evaluate children's use of their sensory systems to maintain postural control under specific conditions. Clinicians can also use this test to examine children's ability to resolve sensory conflict.

Reliability of the P-CTSIB for typically developing children has been reported in two articles. Crowe and colleagues (1990) evaluated the inter-rater reliability of P-CTSIB scores obtained by two examiners assessing simultaneously 24 children ages 4 to 9 years. They reported Spearman rank order correlation coefficients ranging from .69 (Condition 3) to .90 (Condition 5), indicating moderate to excellent inter-rater reliability for the measurement of sway. Westcott and colleagues (1994) also used a sample of 24 children in the same age range to examine the test-retest reliability of the P-CTSIB. The same examiner tested each child on the P-CTSIB on two different occasions, 1 week apart. Spearman's rank order correlation coefficients for test-retest reliability for *sway* measurements of the P-CTSIB feet-together position ranged from .37 (Condition 2) to .70 (Condition 5), indicating poor to moderate reliability. Westcott et al. also reported test-retest reliabilities for *duration* measurements and *combined scores* (created from combination of duration and sway scores into six categories according to specific sensory systems). For this study, however, we focused on measures of postural sway because this is the main outcome of interest in the SOT.

The P-CTSIB was developed to evaluate sensory influences on postural control in the same manner as the SOT (Crowe et al., 1990; Shumway-Cook & Horak, 1986). However, there were no identified studies that examined the relationship between these two tests. We recently conducted a study that examined the concurrent validity of the SOT and the P-CTSIB. Our results illustrated that there is a poor to moderate relationship between the two outcome measures. One of the factors contributing to these results may be low reliability of the P-CTSIB. Another potential factor could be the natural variability seen in children's postural control. Natural variability of postural sway could result in different scores at different times. This may also have an influence on the reliability coefficients calculated for both the P-CTSIB and the SOT. These factors would affect the concurrent validity between the two outcome measures.

Since reported test-retest reliability of the P-CTSIB was low (Westcott, Crowe, Deitz, & Richardson, 1994) we felt it was worthwhile to re-evaluate the test-retest reliability of this measure to determine if reliability was a factor that influenced the concurrent validity of the P-CTSIB and the SOT. In addition, examination of the test-retest reliability is important if therapists are to consider using the P-CTSIB in a clinical setting for evaluative purposes. The objective of this research study was to examine test-retest reliability of P-CTSIB scores obtained by typically developing children taken one week apart.

Methods

This study was performed in conjunction with a larger study to examine the concurrent validity between the SOT and the P-CTSIB. For this reliability study, 15 children (8 girls and 7 boys) volunteered from a group of 46 children who participated in the larger study. We recruited the original volunteer sample by advertising in child care centres, recreational facilities, community centres, and a local community newspaper. Inclusion criteria were that the child's age was within a 6-month upper range for each specified age group. Parents had to commit to attending an evaluation session at a local rehabilitation hospital. Exclusion criteria were (a) a history of current or previous ear infections in the past 6 months; (b) any diagnosed disorders including motor impairment, cognitive impairment, developmental delay, uncorrected visual impairment, or uncorrected hearing impairment; (c) a history of receiving therapy services for postural control difficulties from an occupational, physical, or speech therapist; and (d) strength and range-of-motion values outside typical values as determined by a pre-assessment screening process adapted from Habib and Westcott (1998). No child who volunteered and met these criteria was excluded from the study. The study received ethical approval from the Health Research Ethics Board at the University of Alberta. Parents provided written informed consent for their child's participation. Children's assent was obtained prior to testing.

The first author (L.C.), an experienced pediatric physical therapist, conducted all testing with an assistant. Four assistants participated in data collection. All were physical therapists with at least 3 years of clinical experience.

The examiner introduced the P-CTSIB testing protocol to the children as the "The Snowman Game." Children were instructed to "stand as still as possible as if you were frozen like a snowman." They were tested in bare feet with their feet together and their hands on their hips. The assistant sat on a stool close behind the child but did not touch the child. The P-CTSIB is administered in a similar manner as the SOT except that the six sensory conditions are created by using a visual conflict dome constructed from a paper lantern instead of the sway-referenced visual surround, and an 18" X 18" X 3" piece of medium density T-foam instead of the sway-referenced surface (Figure 4-2). Each child performed two 30-second trials for each of the six sensory conditions in succession. All six conditions were completed sequentially from Condition 1 to Condition 6 during the same session, requiring approximately 20 to 25 minutes. The children received a sticker in between conditions to keep them interested and motivated.

The examiner measured postural sway using a backdrop with lines radiating in one-degree increments from a central axis at the floor. The lines radiated to a maximum of 20 degrees of sway in each direction. The child was positioned beside the backdrop so their medial malleoli were lined up to the vertical line at 0 degrees (Figure 4-3). The examiner recorded the total anterior-posterior sway by using the child's nose or a vertical pointer on the paper dome as a reference point (Crowe et al., 1990). The children were instructed to look at a picture approximately 3 feet away. This assisted the children to visually fixate on an object to maintain their head in the same position and improve the accuracy of the postural sway measurement. The assistant timed the duration of standing balance using a stopwatch. Timing began when the child was in position and the assistant let go of the child. Timing stopped when the child maintained the position for 30 seconds or a postural adjustment was made. A postural adjustment is defined as "removing hands from hips, moving one or both feet from the original position, opening eyes during the eyes-closed condition, or requiring assistance from the examiner to prevent a fall" (Richardson, Atwater, Crowe, & Deitz, 1992, p. 796).

The examiner measured the amount of sway, and recorded sway and duration scores on a data sheet (Appendix A). The assistant gave the child directions, positioned the child, guarded against falls, and timed the duration of standing balance. She also ensured the eyes were kept closed during Conditions 2 and 5. For each condition, we chose the best score of the two trials based on previous test administration guidelines (Westcott et al., 1994). The best trial is defined as the trial with the longest duration, or if both trials have equal duration, the trial with the least amount of postural sway.

To collect test-retest reliability data, the examiner repeated the P-CTSIB testing 1 week after the initial P-CTSIB assessment on the subset of 15 children. The examiner and assistant were unaware of previous test results. One week was chosen as the period between the test and the retest for three reasons. First, Westcott and colleagues (1994) used a 1-week interval in their test-retest study of the P-CTSIB, allowing us to compare our results to their findings. Second, this time period controls for maturation as a potential confounder in test-retest results. Lastly, a 1-week interval made recall of previous test scores difficult for the examiner and assistant. The retest procedures for the P-CTSIB were identical to the P-CTSIB procedures stated earlier. Retest scores of the P-CTSIB were recorded on another data sheet. The retest took approximately 20-25 minutes.

Statistical Analysis

SPSS 12.0 for Windows (SPSS Inc., Chicago, IL, USA) was used for statistical analysis. To determine the test-retest reliability of the P-CTSIB we calculated Intraclass Correlation Coefficients (ICC 3,1) for the postural sway scores for each of the six conditions tested (Shrout & Fleiss, 1979). We also determined 95% confidence intervals around the ICCs. Descriptive statistics of the P-CTSIB scores were also generated (mean, standard deviation, range, minimum, maximum).

Results

Fifteen children (mean age = 6.4 years, SD = 1.8) completed the test-retest of the six conditions of the P-CTSIB. The children included three 3.5-year-olds, six 5.5-year-olds, and six 8-year-olds. Descriptive statistics and test-retest reliability of P-CTSIB postural sway scores are presented in Table 4-1. ICCs for test-retest reliability and 95% confidence intervals are presented in Table 4-2. ICCs ranged from .35 (Condition 5) to .47 (Condition 6).

Discussion

The results of this study indicate that the test-retest of P-CTSIB postural sway scores ranged from poor to fair for the six sensory conditions. These results suggest that P-CTSIB scores are not consistent over two assessments 1 week apart. In addition, the 95% confidence intervals of the ICCs overlapped across the conditions.

These results were lower than those obtained by Westcott and colleagues (1994) for postural sway in the feet-together position except in Condition 2. The test-retest results from their study ranged from poor (r = .37) to good (r = .70). They obtained Spearman rank correlation coefficients of .67, .37, .49, .51, .70, and .58 for Conditions 1 to 6 respectively. The lower scores in our study may be due to differences in sample size. Westcott et al. had a larger sample of children ($N = 24$) which may have contributed to increased variability of scores on the P-CTSIB. Also, each of the six age categories (from ages 4 to 9 years) included 4 children (2 boys and 2 girls). Our sample had three age categories (3.5, 5.5, and 8 years) with 6 children (3 boys and 3 girls) in the two older age groups. The youngest age group included 3 children (1 boy and 2 girls). Although the age range is similar in both studies, the distribution of scores across a greater number of age groupings in Westcott et al.'s study may have also contributed to an increased variability of scores. The greater the variability of scores obtained, the greater the value of the correlation coefficient (Glass & Hopkins, 1996).

Overall test- retest reliability on the P-CTSIB obtained in our study may otherwise be influenced by three factors: (a) attenuation of scores, (b) natural variability of postural sway scores, or (c) measurement error.

It appears that the P-CTSIB may not be sensitive enough to produce adequate variability or range of postural sway scores. The range of scores in each of the conditions only spanned 2 to 5 degrees in both the test and retest (Table 1). On closer examination of individual test and retest scores across the six conditions, we determined the absolute difference between the test and retest score was 0 to 2 degrees. The only exception was for one child in Condition 3 where the difference between the test and the retest score was 3 degrees. The attenuation of the P-CTSIB score range will make the agreement between the test and retest appear low even though test and retest scores may only differ a few degrees.

Our study showed minimal differences in the ICCs across the six conditions. This indicates that the differences between the six sensory conditions did not appear to change the test-retest reliability of the scores. This was an interesting finding since we expected that the test-retest reliability would decrease as conditions became more challenging. In the easier conditions, the children would have decreased postural sway and have less *intra*-individual variability. This would make it more likely for the children to obtain a similar score on the test and the retest which would result in higher correlation coefficients. However, as mentioned previously, there was very little difference in the range and distribution of scores between the six conditions. This decreased the *inter*-individual variability which resulted in lower correlation coefficients. This may be the main reason why the test-retest reliabilities are so similar across the six conditions. Furthermore, it should be noted that the 95% confidence intervals around the ICCs are very wide (Table 2). This makes it very difficult to be certain of the test-retest reliabilities obtained in this study.

Although the range of scores observed in the P-CTSIB scores is minimal, natural variability in the postural control of typically developing children in different sensory conditions may also result in slightly different scores between repeated tests. Brouwer and colleagues (1997) determined that healthy young adults were able to sway comfortably within their limits of stability without losing their balance. This contributes to increased intra-individual variability between test and retest scores. It is important to note that these researchers used computerized dynamic posturography for their testing which is more sensitive than the P-CTSIB and produces a larger range of scores. Accordingly, different postural sway scores could be obtained on repeated tests even if there is only a limited range of scores on the P-CTSIB. Even if scores vary by a few degrees, this could impact the test-retest reliability coefficients calculated for the P-CTSIB.

Lastly, the results from our study may simply indicate that the P-CTSIB is not a very reliable test to evaluate postural sway over time or on repeated measurements. Since inter-rater reliability of the P-CTSIB is moderate to excellent (Crowe et al., 1990), poor test-retest reliability could likely be the result of changes in the testing equipment, differences in the environmental conditions, or measurement error by the examiner from one test session to the next. We were careful to standardize our test procedures, ensuring that the same equipment was used with the children tested in the same positions. The same examiner was also used to test the children in the test and the retest. It is possible that the children may have moved their head position during testing, resulting in inaccurate measurement when the examiner observed the child's nose or the vertical pointer on the paper dome. In addition, visual observation of peak-to-peak sway using the child's nose or vertical pointer on the paper dome as a reference to the degree lines may not be very accurate. Other factors may be differences in the child's effort or concentration on the task.

Conclusion

The findings from this study indicate that test-retest reliability of the P-CTSIB postural sway scores across the six conditions are poor to fair. This confirms our hypothesis that the low concurrent validity results between the P-CTSIB and the SOT may have been influenced by the low reliability of the P-CTSIB. Based on the low test-retest reliability and low concurrent validity with the SOT, the P-CTSIB does not appear to be a good outcome measure to determine sensory influences on postural control or to evaluate sensory organization ability.

The P-CTSIB scoring system needs to be re-evaluated or refined before the test can be used with confidence. Use of a combined score categorizing postural sway and duration measures has shown test-retest reliabilities of .45 to .69 using Spearman's rank correlation coefficients (Westcott et al., 1994). Although the P-CTSIB may not be appropriate for evaluative purposes, this test could potentially be used for discriminative purposes. One study illustrated that children with learning disabilities and motor delays had significantly lower scores on four of six combined score scales using the P-CTSIB (Deitz, Richardson, Crowe, & Westcott, 1996).

There also is a need to develop other reliable and valid clinical outcome measures to examine sensory influences on postural control in children. A few studies have used a portable force-plate system to quantify postural sway scores in different sensory conditions (Gabriel & Mu, 2002; Polatajko & Sullivan, 1987). Gabriel and Mu (2002) obtained test-retest ICCs of .76 to .83 in four sensory conditions (eyes open and closed using a flat surface and a foam surface) among 18 children 5 to 9 years of age using this type of system. Polatajko and Sullivan (1987) measured postural sway in eyes open and eyes closed conditions on a force platform. They found significant differences in the postural sway of 5 children with and 5 children without learning disabilities with eye closure. These studies show there is potential use of a force-plate system to measure the organization of sensory inputs on postural control. These systems may offer a "middle-ground" alternative to the expensive computerized dynamic posturography system used in the SOT and the simple materials used in the P-CTSIB.

The findings from this study are limited to typically developing children in the age groups studied. They cannot be extrapolated to children with postural control difficulties or to children with specific diagnoses. In addition, the test-retest reliability only reflected postural sway scores. Other measures of the P-CTSIB used by the developers of the test, such as duration and combined scores were not evaluated. This study also involved a small sample size.

Further studies could examine the use of the P-CTSIB or a modified force-plate system for discriminative purposes. Studies investigating the natural variability of postural control in children are also warranted. Most importantly, the relationship between steady-state postural sway scores and functional activities in children should be studied in order to provide meaningful information to clinicians and families.

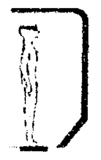
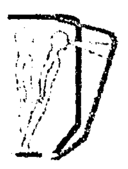
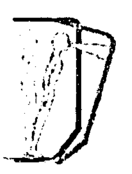
Condition	Diagram	Description	Orientationally Accurate Sensory Systems	Absent or Inaccurate Sensory Systems
Condition 1		Eyes Open Fixed Surface	Vision Somatosensory Vestibular	
Condition 2		Eyes Closed Fixed Surface	Somatosensory Vestibular	Absent Vision
Condition 3		Sway-Referenced Vision Fixed Surface	Somatosensory Vestibular	Inaccurate Vision
Condition 4		Eyes Open Sway-Referenced Surface	Vision Vestibular	Inaccurate Somatosensory
Condition 5		Eyes Closed Sway-Referenced Surface	Vestibular	Absent Vision Inaccurate Somatosensory
Condition 6		Sway-Referenced Vision Sway-Referenced Surface	Vestibular	Inaccurate Vision Inaccurate Somatosensory

Figure 4-1. Six sensory conditions of the Sensory Organization Test (SOT)

Note. From NeuroCom International, Inc. (1999). *Sensory Organization Test (SOT): sensory analysis* [Brochure]. Clackamas, OR: NeuroCom International, Inc. Copyright 1999 by NeuroCom International, Inc. Adapted with permission.

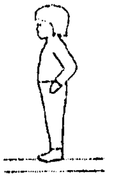
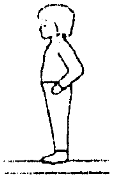
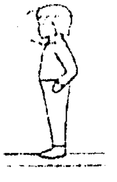
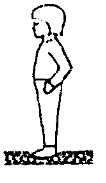
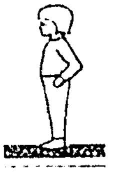
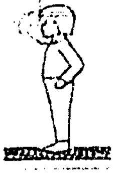
Condition	Diagram	Description	Orientationally Accurate Sensory Systems	Absent or Inaccurate Sensory Systems
Condition 1		Eyes Open Flat Surface	Vision Somatosensory Vestibular	
Condition 2		Eyes Closed Flat Surface	Somatosensory Vestibular	Absent Vision
Condition 3		Visual-Conflict Dome Flat Surface	Somatosensory Vestibular	Inaccurate Vision
Condition 4		Eyes Open Foam Surface	Vision Vestibular	Inaccurate Somatosensory
Condition 5		Eyes Closed Foam Surface	Vestibular	Absent Vision Inaccurate Somatosensory
Condition 6		Visual-Conflict Dome Foam Surface	Vestibular	Inaccurate Vision Inaccurate Somatosensory

Figure 4-2. Six sensory conditions of the Pediatric Clinical Test of Sensory Interaction for Balance (P-CTSIB)

Note. From "Interrater reliability of the Pediatric Clinical Test of Sensory Interaction for Balance," by T. K. Crowe, J. C. Deitz, P. K. Richardson, and S. W. Atwater, 1990, *Physical and Occupational Therapy in Pediatrics, 10*(4), p. 10. Copyright 1991 by Haworth Press, Inc. Adapted with permission.

Figure 4-3. Position of child wearing safety belt during P-CTSIB testing

Table 4-1.

Descriptive Statistics of P-CTSIB Test and Retest Scores

		Mean	SD	Min.	Max.	Range
Condition 1	test	2.1	.8	1	3	2
	retest	1.9	.6	1	3	2
Condition 2	test	3.1	.8	1	4	3
	retest	3.0	.8	2	5	3
Condition 3	test	3.7	.8	2	5	3
	retest	3.9	1.2	2	7	5
Condition 4	test	2.1	.5	1	3	2
	retest	2.4	.7	1	4	3
Condition 5	test	3.7	1.0	2	5	3
	retest	3.9	1.1	3	7	4
Condition 6	test	4.3	.8	3	6	3
	retest	4.5	1.1	3	7	4

Table 4-2.

Intraclass Correlation Coefficients and 95% Confidence Intervals of the P-CTSIB Test and Retest Scores

		95% Confidence Interval	
		Lower Bound	Upper Bound
Condition 1	.43	- .08	.76
Condition 2	.44	- .10	.77
Condition 3	.42	- .11	.76
Condition 4	.37	- .11	.73
Condition 5	.35	- .19	.73
Condition 6	.47	-. 04	.78

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CHAPTER 5

CONCLUSION

Summary of Results

The results of this study provide valuable information for clinicians and researchers regarding the psychometric properties of the P-CTSIB. The P-CTSIB was developed based on the SOT, which is considered the "gold standard" for the objective measurement of the influence and organization of visual, somatosensory, and vestibular inputs for postural control (El-Kashlan, Shepard, Asher, Smith-Wheelock, & Telian, 1998; Gabriel & Mu, 2002; Keshner, 1994). The concurrent validity of P-CTSIB and SOT scores for the six sensory conditions, however, was poor to moderate (r = -.11 to -.69) indicating that the P-CTSIB cannot be used as a proxy measure for the SOT.

This study also presents additional information on the test-retest reliability of the P-CTSIB. Test-retest reliability of P-CTSIB scores taken 1 week apart by the same examiner was poor to fair (ICC = .35 to .47) for the six sensory conditions. These correlation coefficients were lower than a previous study that examined test-retest reliability of the P-CTSIB (Westcott, Crowe, Deitz, & Richardson, 1994). The low test-retest reliability likely influenced the degree of concurrent validity between the P-CTSIB and the SOT. Based on the concurrent validity and test-retest reliability results, the P-CTSIB does not appear to be a good outcome measure to evaluate sensory system influences on postural control or sensory organization ability in typically developing children.

This study yielded very interesting findings on the influence of anthropometric factors on postural control. The results suggested postural control in children became worse as their head circumference increased relative to their height. Furthermore, it illustrated that the height / head circumference ratio was a better predictor of scores on the SOT than P-CTSIB scores. This indicated that postural control in children might depend more on when they reach certain body dimensions or proportions versus reaching a specific chronological age.

Lastly, this study illustrates that children's postural control responses vary according to different sensory conditions. It also shows that the postural control of children aged 3.5, 5.5, and 8 years may be more similar in certain environments than expected.

The results and conclusions from this study only reflect postural control in typically developing children. They cannot be extrapolated to children with postural control difficulties or to children with specific diagnoses.

Clinical Implications

The findings from this study highlight the need to re-evaluate or refine the P-CTSIB before it can be used with confidence in a clinical setting. This study also brings attention to the limited clinical measures that are available to clinicians to examine sensory system constraints on postural control. There is a need to develop other reliable and valid clinical outcome measures in this area.

The results also suggest that there is natural variability observed in postural control. Children may be able to sway comfortably within their limits of stability without losing their balance. This can contribute to the challenge of creating a useful and reliable measure for postural control.

Currently, the SOT appears to be the only reliable outcome measure that is able to provide objective quantitative information about how children use and organize sensory inputs for postural control. It may be that physiological outcome measures using advanced technical equipment capable of very sensitive measurement cannot be replicated by clinical measures using simple materials.

This research study shows that postural control in children is influenced by many factors including environmental conditions, anthropometric characteristics, and developmental level. This illustrates the need for physical therapists to consider a wide variety of systems that may be involved in maintaining stability. It is also important for therapists to understand what components of postural control are being tested using different outcome measures or clinical tests. Knowledge of children's use and organization of sensory systems as they develop will assist therapists in their evaluation of postural control in children.

Dissemination of Results

The results and clinical implications of this study will be disseminated in a variety of ways. Chapters 3 and 4 will be submitted to peer-reviewed journals within 6 weeks of the thesis defense. The theory and research review in Chapter 2 was presented at a conference for community pediatric physical and occupational therapists on August 27, 2004 in Edmonton. This information may be shortened and submitted to a journal for publication. The preliminary findings on the concurrent validity between the P-CTSIB and the SOT from Chapter 3 were presented at the Glenrose Rehabilitation Hospital Research Day on October 28, 2004 in Edmonton. The final results and conclusions of this study from Chapters 3 and 4 will be presented to physical and occupational therapists from both the community and the Glenrose Rehabilitation Hospital on April 27, 2005. An abstract for podium and poster presentations based primarily on content from Chapter 3 will be submitted to the American Academy for Cerebral Palsy and Developmental Medicine in January 2006. Families of children who participated in the study and who indicated an interest in the results will be provided a summary of findings and a synopsis of the information.

Implications for Future Research

More research in the area of sensory influences on steady state postural control in children needs to be done, particularly with larger sample sizes using standardized, reliable, and valid outcome measures. It is still unclear how children use their sensory systems to interpret conditions in the environment and how they organize sensory information for postural control. In recent years, the focus of research in this area appears to have shifted more towards examining anticipatory postural responses (Assaiante, Woollacott, & Amblard, 2000; Liu, Zaino, & Westcott, 2000; Schmitz, Martin, & Assaiante, 1999; Witherington et al., 2002). While anticipatory research is a growing area of interest, it is still critical to establish how sensory systems influence postural control development in steady state stance. In addition, further research into how sensory information is interpreted and organized may contribute to understanding how children perceive different environmental conditions for anticipatory postural adjustments.

An area that also warrants further research is the hypothesized transition period between 4 and 6 years of age. The research is ambiguous in this area. Some studies suggest the transition period may not occur in as narrow an age period as is suggested in the literature (Shumway-Cook & Woollacott, 1985; Woollacott, Debu, & Mowatt, 1987).

Additional research on anthropometric measurement and its relationship to postural control would be valuable. Natural variability in postural control should be studied further in typically developing children and in children with postural control difficulties. Examination of the P-CTSIB or SOT's relationship to function would also help to determine the validity of these two outcome measures. Finally, more studies on the discriminatory function of P-CTSIB would be beneficial to determine if this measure is useful in identifying children with postural control difficulties.

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APPENDIX A:

DATA COLLECTION FORM

DATA COLLECTION FORM

Date: _______________ ID # _____

Pre-screening test:

☐ squat

☐ spinal flexibility

Anthropometric Measures:

	Height (cm)	Weight (kg)	Head circumference (cm)	Foot length (cm)
Measurement 1				
Measurement 2				
Mean				

P-CTSIB:

	Trial 1		**Trial 2**	
Sensory Condition	Duration (sec)	Postural Sway (total degrees)	Duration (sec)	Postural Sway (total degrees)
1. Eyes Open				
2. Eyes Closed				
3. Dome				
4. Eyes Open, Foam				
5. Eyes Closed, Foam				
6. Dome and Foam				

SOT Equilibrium Scores: see printout from computer

Comments: