The purposes of this study were to describe the performance of 40 children aged 4 and 5 years on the Pediatric Clinical Test of Sensory Interaction for Balance (P-CTSIB) and to determine whether age- and gender-related differences were present. The P-CTSIB measures standing balance when sensory input is systematically altered. Kruskal-Wallis one-way analyses of variance by ranks ($p \leq 0.05$) were used for comparisons by age and gender. When the 4-year-olds were compared with the 5-year-olds, significant duration differences were found in 4 of the 6 conditions in the heel-toe position of the P-CTSIB. The age-related differences on the remaining 2 heel-toe conditions, as well as on Condition 6 of the feet-together position, approached significance. Gender differences with 4-year-olds and 5-year-olds combined were statistically non-significant in all instances; however, girls performed better on 9 of the 12 conditions of the P-CTSIB. The results indicate that the feet-together position can discriminate between children without balance deficits and children with balance deficits. The heel-toe position is difficult for children aged 4 and 5 years without balance deficits and consequently has limited diagnostic value for this age group.
cupational therapist's experience and skill in eliciting, observing, and interpreting balance responses become critical factors in the assessment of postural stability. These observations may not provide enough information about sensory or motor strategy selection, particularly when a child demonstrates more subtle deficits in motor coordination and balance.

An assessment tool that provides information about sensory contributions to balance could greatly improve the occupational therapist's ability to assess and treat children with balance deficits. However, more information is needed about how children without balance deficits use sensory inputs to select available motor strategies when placed in sensory conflict situations.

Literature Review

Nashner (1982) described two components of the postural reaction. The first component, sensory organization, was defined by Nashner as "those processes which determine the timing, direction, and amplitude of corrective postural actions based upon the convergence of orientation information from visual, vestibular and somatosensory inputs" (p. 358). The second component, muscle coordination, referred to "processes which determine the temporal sequencing and the distribution of contractile activity among the muscles of the legs and trunk which generate supportive reactions" (p. 358). Nashner and Woollacott (1979) described computerized posturography and electromyography (EMG) studies that evaluated selection of sensory inputs. When subjects are placed on a platform with the option of a movable platform surface (altered somatosensory input) and the option of a movable visual surround (altered visual input), the relative influence and weighting of support surface, visual inputs, and vestibular inputs can be systematically assessed. A computerized record is made of body sway in different sensory conditions and muscle activity in response to perturbations of balance.

Forssberg and Nashner (1982) used computerized posturography and EMG techniques to describe an interaction of vestibular, proprioceptive, and visual inputs, the weighting of which is context-dependent, to trigger balance reactions. They reported that children younger than age 7 1/2 years do not seem to have a systematic method for weighting the most appropriate sensory system for the maintenance of balance. Therefore, children younger than age 7 1/2 years may sway and lose their balance in the presence of conflicting visual and somatosensory inputs. Using similar laboratory procedures, Shumway-Cook and Woollacott (1985) found a stagelike transition from immature to mature postural responses in nondisabled children. The greatest variability in postural responses (and inability to correctly recognize conflicting sensory information) was present in children aged 4 to 6 years, with mature postural control emerging between ages 7 and 10 years. Children shifted from a primary dependence on visual input to a more adultlike dependence on a combination of visual and somatosensory input. Older children showed more mature timing and strategy selection in their motor responses. The authors concluded that the variability in performance found in the children aged 4 to 6 years was due to their developing more mature motor strategy coordination as well as the ability to appropriately select from a variety of sensory inputs.

Romero (1990) evaluated trunk flexor muscle strength in 108 children aged 3 to 6 years without balance deficits. Significant differences in strength existed for all groups, with the greatest gain occurring between the ages of 4 and 5 years. Romero hypothesized that this large increase in scores might have reflected the children's improved ability to coordinate the muscular action, rather than structural or biomechanical factors. This improved ability to coordinate the muscular action responsible for postural adjustments corresponds closely to Shumway-Cook and Woollacott's (1985) findings of the emergence of more sophisticated motor strategy coordination for postural responses in this age group.

Shumway-Cook and Horak (1986) adapted the computerized posturography procedures used in the above studies for use in a clinical environment. In their test, the Clinical Test of Sensory Interactions for Balance (CTSIB), standing balance is observed under the following six conditions:

1. Normal vision and support surface
2. Normal support surface, vision eliminated
3. Normal support surface, altered vision
4. Altered support surface, normal vision
5. Altered support surface, vision eliminated
6. Altered support surface, altered vision

Duration of stance and quality of movement are measured. Shumway-Cook and Horak (1986) stated that it is important to know which sense a person depends on most for sway orientation and how well a person can adapt to reliance on the various senses in situations of intersensory conflict.

Crowe, Deitz, Richardson, and Atwater (1990) adapted the CTSIB to assess sensory contributions to standing balance in children. The pediatric version is called the Pediatric Clinical Test of Sensory Interaction for Balance (P-CTSIB). Test procedures were standardized and interrater reliability was examined with 24 children aged 4 to 9 years without balance deficits. The results of this study indicated that two raters could reliably score sway and nominal sway categories. Deitz, Richardson, Atwater, Crowe, and Odiorne (1991) examined the P-CTSIB performance of 109 children aged 6 to 9 years without balance deficits. Two foot positions, feet-together and heel-toe, were used. The investigators found that in general, all children aged 6 to 9 years could maintain balance in all sensory conflict situations in the feet-together position.
The heel-toe position resulted in more variability, with progression of difficulty related to manipulation of visual cues. No clear developmental progression was found for the P-CTSIB, although the youngest children scored the same or lower than the oldest children for duration of stance in all conditions. Results related to differences in gender were also inconclusive. The authors recommended further research on larger numbers of children with and without balance deficits before drawing conclusions about balance deficits in specific children.

The P-CTSIB can provide specific information on sensory selection strategies and their relationship to postural responses that has not been readily available to occupational therapy clinicians. Further descriptive information on the P-CTSIB is needed before it can be used reliably with preschoolers and kindergartners. The purpose of this study, therefore, was to describe the performance of 4-year-old and 5-year-old children without balance deficits on the P-CTSIB. The two research hypotheses tested were as follows:

1. There is a significant difference between the performance of 4-year-olds and that of 5-year-olds on the P-CTSIB.
2. There is a significant difference between the performance of 4-year-old and 5-year-old girls and that of 4-year-old and 5-year-old boys on the P-CTSIB.

Method

Subjects

Subjects were 40 preschool and kindergarten children whose ages ranged from 4 years 0 months to 5 years 11 months. They were recruited from Headstart preschool programs, a private preschool and day-care facility, a private kindergarten, and a public school kindergarten in Seattle. Information on parental educational level was obtained for 38 of the mothers and 33 of the fathers. The median level for both groups was 2 years of college.

Permission slips describing the testing procedures were sent home, and the children who received permission to participate were divided into four categories: 4-year-old girls, 4-year-old boys, 5-year-old girls, and 5-year-old boys. Ten subjects were randomly selected from each of these groups. The 4-year-old age group contained 13 white children, 6 black children, and 1 Hispanic child; the 5-year-old age group, 16 white children and 4 black children.

All parents signed consent forms that were approved by the University of Washington Human Subjects Committee. Parents indicated by questionnaire responses that all children were free of major developmental concerns such as serious problems with motor coordination, seizures, neurological problems, and learning or physical disabilities. In addition, all children passed a biomechanical screening consisting of strength and range-of-motion tests of the trunk and lower extremity before the balance tests were administered.

Instrumentation and Procedure

Subjects were barefoot for all testing. The P-CTSIB was administered as part of a battery of balance tests including tiltboard tip and one-foot balance. Information regarding the latter two tests is not reported in this article. The order of administration of all tests was randomized across subjects.

The P-CTSIB evaluates duration of standing balance and amount of body sway under six different sensory conditions. Combinations of three visual and two support surface variables are used. The visual variables are (a) eyes open, normal visual input; (b) eyes closed, visual input eliminated; and (c) sway-referenced vision, in which a visual conflict dome moves in phase with the child's head movement and prevents visual orientation to the environment. Peripheral vision is restricted at the top, bottom, and sides, as described by Shumway-Cook and Horak (1986). A tape mark is placed on the forward part of the dome as a visual reference point. The support surface variables are (a) standing on a hard, flat surface: normal somatosensory input; and (b) standing on a firm, compliant medium-density foam: inaccurate somatosensory input.

In the first three conditions, the subject stands on a normal surface with eyes open (Condition 1), with eyes closed (Condition 2), and with the visual conflict dome (Condition 3). The three visual conditions are repeated with the subject standing on the foam (Conditions 4, 5, and 6). The difficulty of the task is thought to increase with each condition as sensory information is systematically altered. Conditions 5 and 6 are considered to be the most difficult because visual and somatosensory input are eliminated or compromised and thus the child must rely primarily on the vestibular system to cue a motor response for maintenance of balance.

The six conditions were administered in two positions: (a) feet together, medial malleoli touching; and (b) heel-toe (the preferred foot is placed behind the nonpreferred foot with the toes touching the heel). Thus, 12 conditions were tested. The six conditions for each foot position were always administered in chronological order.

Each of the six conditions was tested two times in each of the heel-toe and feet-together positions. The subject stood with hands on hips, and duration of standing was measured until the subject had maintained the position for 30 sec or made a postural adjustment. A postural adjustment was defined as removing hands from hips, moving one or both feet from the original positions.
opening eyes during the eyes-closed conditions, or requiring assistance from the examiner to prevent a fall.

A backdrop with lines radiating in 1° increments from a central axis at the floor was placed behind the subject to measure amount of sway, as shown in Figure 1. A maximum of 40° total sway (20° in each direction) was measured. Three additional nominal sway scores were possible: (a) inability of the child to assume the condition position (i.e., the examiner could not let go of the child); (b) a fall during the test condition in which the child made no postural adjustment (a "timber" fall); and (c) inability of the child to stand in the condition position longer than 3 sec. The latter made it difficult or impossible for the examiner to determine the degrees of sway that occurred because balance was maintained so briefly. For the feet-together position of the P-CTSIB, total anterior and posterior degrees of sway were recorded. In the heel-toe position of the P-CTSIB, total lateral degrees of sway were recorded. Interrater reliability was examined for the sway measurement in a previous study (Crowe et al., 1990). Spearman rank order correlations were used as indexes of reliability and ranged from .69 for P-CTSIB feet-together Condition 3 to .92 for P-CTSIB heel-toe Conditions 1 and 5.

On each of the six P-CTSIB feet-together and six P-CTSIB heel-toe conditions, the best of the two trials was recorded. The best trial was defined as the trial with the longest duration or, if the durations were the same, the trial with the smallest sway. Though a quality measure was included in the adult version of this test, previous research (Crowe et al., 1990) suggested that the quality measure was not reliable. Therefore, quality data are not reported for the children. Two examiners were required to administer the P-CTSIB. The primary examiner recorded sway, and the secondary examiner positioned the subject, guarded against falls, and recorded the duration of stance. A digital stopwatch was used to record time. Other equipment included a 6-ft backdrop with degree lines (to measure postural sway), an 18-in by 18-in by 3-in piece of medium density foam, a visual conflict dome, and a head pointer. Paper surgical caps were placed on the subjects' heads for sanitary reasons. The total time required to administer the test battery was approximately 30 min.

Examiners

The first and second authors served as primary examiners. Both had more than 8 years of clinical pediatric experience and participated in development of the test.

Five people served as secondary examiners. Two (the third and fourth authors) were registered occupational therapists with pediatric experience and three were occupational therapy or physical therapy students. All secondary examiners received training and established procedural reliability before participating in data collection. In addition, timing of conditions was compared with that of experienced secondary examiners. Timing agreement had to be within 1 sec.

Results

Descriptive data were examined first for duration and second for sway. Because of the skewed score distributions for both duration and sway data, medians and low and high scores are presented as well as means and standard deviations. Additionally, scores in the 25th percentile are presented for duration to assist in clinical interpretation of scores. For sway, scores in the 75th percentile are presented, because a high score is more indicative of dysfunction. Descriptive data for Conditions 5 and 6 for the feet-together position and Conditions 1 through 6 for the heel-toe position duration are presented in Table 1. Data are not presented for Conditions 1 through 4 for the feet-together position because all but 6 children could maintain balance for the maximum time for these conditions.

Descriptive data for degrees of sway are shown in Table 2. In some conditions the sample sizes are smaller than those reported for duration because sway was not measured unless a child maintained balance for more than 3 sec. For data on the percentages of children (for each age and condition) who could maintain balance for more than 3 sec, see Figure 2.

A Kruskal-Wallis one-way analysis of variance by
Table 1

Subjects’ Standing Balance Duration on the P-CTSIB

<table>
<thead>
<tr>
<th>Age</th>
<th>Duration (in sec)</th>
<th>Low/25th percentile</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>F+E-Together Position</td>
<td></td>
</tr>
<tr>
<td>4-yr-olds</td>
<td>24</td>
<td>30</td>
<td>9</td>
</tr>
<tr>
<td>5-yr-olds</td>
<td>27</td>
<td>30</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Heel-Together Position</td>
<td></td>
</tr>
<tr>
<td>4-yr-olds</td>
<td>27</td>
<td>30</td>
<td>6</td>
</tr>
<tr>
<td>5-yr-olds</td>
<td>29</td>
<td>30</td>
<td>4</td>
</tr>
</tbody>
</table>

Note: Condition 1: Normal support surface, normal vision; Condition 2: Normal support surface, vision eliminated; Condition 3: Normal support surface, altered vision; Condition 4: Altered support surface, normal vision; Condition 5: Altered support surface, vision eliminated; Condition 6: Altered support surface, altered vision.

Table 2

P-CTSIB Sway in Degrees by Age

<table>
<thead>
<tr>
<th>Age</th>
<th>M</th>
<th>Median</th>
<th>SD</th>
<th>Low/75th percentile</th>
<th>High</th>
<th>n</th>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4-yr-olds</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>1/5/5</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>5-yr-olds</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>0/5/5</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>4-yr-olds</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>1/6/9</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>5-yr-olds</td>
<td>4</td>
<td>4</td>
<td>1</td>
<td>2/6/8</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>4-yr-olds</td>
<td>4</td>
<td>4</td>
<td>2</td>
<td>2/5/8</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>5-yr-olds</td>
<td>5</td>
<td>3</td>
<td>2</td>
<td>2/4/9</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>4-yr-olds</td>
<td>5</td>
<td>4</td>
<td>1</td>
<td>3/5/8</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>5-yr-olds</td>
<td>6</td>
<td>6</td>
<td>3</td>
<td>3/7/17</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>4-yr-olds</td>
<td>7</td>
<td>7</td>
<td>2</td>
<td>3/8/11</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>5-yr-olds</td>
<td>7</td>
<td>7</td>
<td>2</td>
<td>4/8/12</td>
<td>20</td>
<td></td>
</tr>
</tbody>
</table>

Note: Condition 1: Normal support surface, normal vision; Condition 2: Normal support surface, vision eliminated; Condition 3: Normal support surface, altered vision; Condition 4: Altered support surface, normal vision; Condition 5: Altered support surface, vision eliminated; Condition 6: Altered support surface, altered vision.

Heel-Toe Position

This foot position was much more difficult for the subjects than the feet-together position. In Condition 6, only 6 of the 40 subjects were able to balance for more than 3 sec.

Analysis of duration by age (see Table 3) revealed significant differences on Conditions 1, 2, 4, and 6. Conditions 3 and 5 approached significance ($p < .09$ and $p < .06$, respectively). Analysis of duration by gender did not reveal any significant differences between boys and girls.

Feet-Together Position

In Conditions 1, 3, and 4, all 40 subjects were able to balance for the full 30 sec. In Condition 2, three 4-year-old girls balanced for 4, 8, and 16 sec; two 4-year-old boys balanced for 20 and 26 sec; and one 5-year-old girl balanced for 22 sec. The remaining 34 subjects balanced for 30 sec; in Condition 5, 12 of the 40 subjects balanced for fewer than 30 sec; in Condition 6, 7 of the subjects balanced for fewer than 30 sec. No significant differences in duration were found for gender or age for all feet-together conditions. However, for Condition 6, the duration difference between 4-year-olds and 5-year-olds approached significance ($p < .06$). Analysis of sway by age and by gender revealed no significant differences between 4-year-olds and 5-year-olds or between boys and girls.
Discussion

Feet-Together Position

Most of the subjects were able to balance for the maximum amount of time on Conditions 1 through 4, and there was limited variability between subjects. Conditions 5 and 6 were more difficult, and subjects showed more variability in performance on these conditions. Conditions 5 and 6 require a primary dependence on the vestibular system for maintaining balance. Although Condition 6, with unreliable visual and somatosensory input, is assumed to be the most difficult condition of the test, the subjects in this sample balanced for less time in Condition 5, where vision is absent and somatosensory input is unreliable. However, the difference was not significant. This result may suggest that, as Shumway-Cook and Woollacott (1985) found, 4-year-olds and 5-year-olds depend more on vision to mediate their balance response.

Conditions 2, 5, and 6 were the only conditions that demonstrated any variability. The two eyes-closed conditions (Conditions 2 and 5) were among the most difficult for the subjects. Four-year-olds experienced more difficulty with these two conditions than did 5-year-olds, which may reflect an increased ability of 5-year-olds to select other sensory inputs to maintain balance. In general, the feet-together position does not discriminate well between 4-year-olds and 5-year-olds or between boys and girls, mainly because much of the test can be easily accomplished by most children without balance deficits in this age group.

Heel-Toe Position

For each condition of the heel-toe position, certain children were unable to assume and maintain the position for 1 sec or more. From the trends of the median scores (see Table 1), it appears that the availability of visual cues affected standing balance duration. The decrease in scores from Condition 1 to Condition 2 may be related to the elimination of visual cues in Condition 2. Condition 4 introduces an unreliable support surface; however, with vision restored in this condition, performance improves over Condition 3. It appears that as long as normal visual input is available, children aged 4 and 5 years can generally override unreliable somatosensory cues to maintain
balance. However, as seen in Conditions 5 and 6, when visual input is absent or conflicting and inaccurate, these children seem to be unable to disregard the inaccurate input and select vestibular inputs to maintain balance.

In all conditions, 5-year-olds performed better than 4-year-olds, suggesting an overall maturation effect. When comparing the performance of children aged 6 to 9 years on the P-CTSIB (Deitz et al., 1991) with that of the subjects in this study, we observed that the 5-year-olds appeared to be more similar to the 6-year-olds than they were to the 4-year-olds. Proportionately fewer 4-year-olds and 5-year-olds were able to maintain their balance in the presence of sensory conflicts when compared with the older age groups. Ninety percent of the children aged 4 or 5 years were able to maintain the heel-toe position for more than 3 sec in Condition 1, as opposed to all but 1 of the 109 children aged 6 to 9 years. This finding probably indicates that assuming the heel-toe position is difficult for some children in this younger age group. When the sensory conflict conditions were administered, many more children aged 4 or 5 years than those aged 6 to 9 years balanced for 3 sec or fewer or were unable to assume and maintain the position. This finding appears consistent with Shumway-Cook and Woollacott's (1985) finding that a transition in sensory selection strategies occurs from age 4 years to age 6 years. A few children appear to have completed the transition at ages 4 years and 5 years; however, many more children are balancing proficiently at age 6 years, with some improvement up to age 9 years. The high degree of variability in scores for 4-year-olds and 5-year-olds on Conditions 2 through 6 may reflect that children in these age groups are at different stages in this transition and do not yet have a systematic sensory selection strategy.

The P-CTSIB heel-toe position appears to be difficult for 4-year-olds and 5-year-olds for several reasons. Reliance on the visual system to mediate the balance response appears to be an important reason. Additionally, biomechanical and motor control factors must be considered. Children's shorter stature requires more rapid and frequent corrections of sway motion (Forsberg & Nashner, 1982). The heel-toe position requires the ability to balance on a very narrow base of support as well as the fine coordination of ankle and hip strategies. As Black, Wall, and Nashner (1983) found in adults with vestibular deficits, use of appropriate motor strategies in an altered sensory environment depends on the ability to use vestibular input appropriately. Young children who cannot yet select among competing sensory inputs may be similarly compromised in their ability to select an appropriate motor strategy. Forsberg and Nashner (1982) noted that children younger than age 7½ years do not have a systematic method for weighting the most appropriate sensory inputs. Instead, young children may randomly change the weighting of support surface, vestibular, and visual inputs. As a result, performance in balance-related tasks with children younger than age 7½ years shows more variability than with children older than age 7½ years.

Clinical Implications

Most of the children in this sample were able to maintain balance in the feet-together position under all sensory conditions and had mean total sway of 7° or less. If a child is unable to balance in sensory conflict situations in the feet-together position or demonstrates increased body sway or both, this may indicate that difficulties in sensory selection strategies result in inability to coordinate motor strategies for standing balance. The feet-together position of the P-CTSIB, therefore, can discriminate between children with age-appropriate balance responses and those with balance deficits. The heel-toe position was much more difficult for the 4- and 5-year-olds, as indicated by the 25th percentile scores. With the exception of Conditions 1 and 4, no 25th percentile score is higher than 4 sec. Because of the difficulty experienced by the children without balance deficits on this task, the heel-toe position cannot be used diagnostically for children aged 4 and 5 years.

Directions for Future Research

The relationship of sensory environment to motor strategy selection should be explored, as should the relationship of various body size parameters to standing balance. A more reliable measurement system for motor strategies also should be developed, and the method for measuring sway should be further examined. Further testing of the P-CTSIB on a larger number of children both with and without a variety of neuromotor and sensorimotor deficits is also necessary.

Acknowledgments

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References


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