Inquiro, the UAB undergraduate science research journal

Volume 2007 | Number 1 Article 15

2007

Test-Retest Reliability of Computerized Dynamic Posturography in Children with and without Cerebral Palsy

Jennifer Yasu Stannard

BIOLOGY

Test-Retest Reliability of Computerized Dynamic Posturography in Children with and without Cerebral Palsy

Jennifer Yasu Stannard

There is little in published literature about motor control tests, and no published studies on the performance of children with cerebral palsy. The MCT is an important test for therapists to use with children with cerebral palsy because it measures response to unexpected platform movements. It has been established that children with cerebral palsy have neuromuscular deficits, and it would be helpful for therapists to be able to measure response to these perturbations so they can design exercises that would better equip the children to function in an unpredictable world. Forssberg and Nashner (1981) studied the response of normal children to a sudden forward or backward movement of the support surface using a movable force platform and surface electromyography (EMG). They found that the latencies of children below 7 ½ years of age were more erratic and slower than the latencies demonstrated by adults in response to the stimulus. There was also a high degree of variability in the children's EMG adjustments among the trials conducted, suggesting that younger children might randomly change the weighting of support surface, vestibular, and visual input when responding to sudden disturbances. No test-retest reliability was done for this study, and no studies addressing the response of children with cerebral palsy to a motor control test were found.

To enable comprehensive balance testing of children with CP, the test-retest reliability of the SOT and MCT must be established. These results will increase confidence in the use of these measures to describe postural control abilities. Since the SOT has been proven reliable in typical children, we hypothesize that these tests will also be reliable in children with cerebral palsy.

INTRODUCTION

Children with Cerebral Palsy (CP), frequently have difficulty maintaining balance, which decreases their ability to stand, sit upright, and walk. Standing balance is achieved through the interaction of three sensory systems: vestibular, somatosensory, and visual. The vestibular system uses input from the semicircular canals and otoliths in the inner ear to give information about head position and movement and subsequent postural adjustments. Movement of the head is detected by the semicircular canals, which sense the bending of sensory hair cells in response to movement of the endolymph (the fluid that fills the membranous labyrinth within the semicircular canals) (Lundy-Ekman, Laurie 2005b). The somatosensory system uses input from multiple skin, joint, and muscle receptors to detect and control musculoskeletal movement (Lundy-Ekman, Laurie 2005a). The visual system uses information from the rods, cones, and central pathways to produce images (sight). Gaze stabilization during head movement is achieved by the interaction between the visual and vestibular systems. This interaction prevents the world from appearing to bounce or move during activities such as walking (Lundy-Ekman, Laurie 2005b). In order to balance in a given environment, a person must be able to properly utilize and integrate the input from the three systems. Children with CP are known to have neuromuscular impairments characterized by abnormal muscle tone (i.e., their muscles are too stiff or too loose all the time). Although peripheral receptors for vision and vestibular function are typically intact, whether children with CP are able to appropriately integrate these systems for balance is unknown.

Computerized Dynamic Posturography provides objective data about the contribution of the three sensory systems in an individual's ability to balance. The Smart EquiTest (NeuroCom) is a machine which allows the experimenter to observe postural reactions as the environment is manipulated. The Sensory Organization Test (SOT) provides orientationally inaccurate input (i.e., movement of the visual surround and/or support surface) and the Motor Control Test (MCT) provides a platform perturbation. The SOT assesses whether the subject relies on one of the sensory systems above the others, is deficient in one or more systems, or is able to properly integrate the information from the three systems to maintain balance. Additionally, the SOT gives information about which strategy the subject is using to maintain balance (i.e., whether rotation of the body to stay upright occurs primarily about the hip or ankle joints). Ankle strategy is typically employed when slow adjustments are required and the center of gravity (COG) can be kept near the center of the support surface. Hip strategy, on the other hand, is usually used when rapid adjustments are needed and the center of gravity is near the perimeter. Ankle strategy is typically used if the support base is broad, while hip strategy is usually employed when the support base is narrow. Deficiencies in sensation could lead subjects to use a strategy for balance that is not optimal (NeuroCom International, Inc. 2005). The MCT measures the ability to maintain balance when the support surface is suddenly moved forward or backward. The amount of time between the onset of the stimulus and the muscular response employed to maintain balance is measured. While some studies have assessed the performance of children with CP on Computerized Dynamic Posturography tests (Hirabayashi, S. and Iwasaki, Y. 1995; Liao, H. F., Jeng, S. F., Lai, J. S. et al., 1997), none have addressed the issue of test-retest reliability for this population. Very few results of the MCT in the pediatric population have been reported, and no results have been reported for pediatric cerebral palsy patients.

When a test gives similar results over a specified period of time (usually a week or more), the test is considered reliable. Greater similarity between the results of two tests indicates higher reliability. If the reliability is not established, there is no way of knowing whether a change in test results is due to machine error or subject learning as opposed to intervention (i.e. physical therapy) that the subject may have received between the two tests. Thus, it is extremely important for tests that will be used for clinical purposes to be considered reliable both so that specific interventions can be designed and determinations may be made regarding the effectiveness of that intervention. A general guideline for interpretation of reliability coefficients is that below 0.50 is "poor reliability"; 0.51-0.75 is "moderate reliability" and above 0.75 is "good reliability" (Portney and Watkins chapter 5). The purpose of this study is to assess the reliability of the SOT and MCT as objective measures of balancing abilities and strategies among both children with cerebral palsy and nondisabled children.

Children with cerebral palsy typically have much poorer balance than their nondisabled counterparts (Cherng, R. J., Su, F. C., Chen, J. J. et al., 1999; Liao, H. F. and Hwang, A. W. 2003; Liao, H. F. et al., 1997; Rose, J., Wolff, D. R., Jones, V. K. et al., 2002). The cause of this balance deficit has been the subject of several studies because it is thought that if balance could be improved via physical therapy or other intervention, walking ability would also improve. Liao et al. (2001) suggested that postural stability, especially when standing with eyes closed, was a good predictor of walking function in children with CP. In an earlier paper, Liao and colleagues (1997) found that weight shift balance also seemed to be related to walking function and that slow walking speed in children with cerebral palsy was likely due to an accumulation of multiple deficits, including poor motor control and balance function, high physiological cost associated with walking, and degree of hypertonus (higher hypertonus was related to slow walking speed in this study). Cherng and colleagues (1999) found that children with CP have significantly poorer balance than age-matched nondisabled children, but were unable to determine whether the problem was poor integration of sensory input or poor motor control. The SMART EquiTest will provide stability scores that will distinguish between balance deficits due to the inability to use a sensory system (i.e., vision, somatosensory, vestibular) versus those due to the inability to appropriately integrate all systems. These studies all relied upon data from some type of SOT system. Therefore, the SOT will provide important information that may guide interventions for children with CP.

The development of sensory strategies used for balance differs between children with CP and typically developing children. Hirabayashi and colleagues (1995) found that vestibular function for balance is not completely mature even in 14-15-year-olds. Rine et al. (1998) found that the ability to use somatosensory input to maintain postural control is mature by 6 years of age, and that there is a transitional period between 3 and 7 ½ years of age during which a more integrated, mature approach to postural control occurs. Similarly, Woollacott and Shumway-Cook (1990) suggested that strong dependence on visual cues between ages 2 and 5 represents a time of fine-tuning the visual system in preparation for the shift to dependence on all 3 systems. In an earlier paper, Shumway-Cook and Woollacott (1985) suggested that children appear to undergo a modification from somewhat random muscular responses and strong dependence on visual cues to fine-tuned muscular responses and an increased dependence on the somatosensory and vestibular systems around 4-6 years of age. Foudriat and colleagues (1993) found that children under 3 years of age tend to rely primarily on the visual system, the somatosensory system is utilized more starting around age 3, and the use of the vestibular system develops more slowly and is not mature even around age 6 (the oldest group of children tested). Although typical development of balance is characterized by a shift from primarily visual to the integration of the visual, vestibular, and somatosensory systems, Rose et al. (2001) found that children over age 3 with CP continue to rely heavily on vision to maintain balance. Furthermore, they found that balance does not tend to improve with age in children with CP as it does in their nondisabled counterparts.

The SOT appears to be an ideal way to assess the underlying causes of balance deficits in children with CP, but the reliability of the system for this population is unknown. In their review of available balance assessment tools, Westcott and colleagues (1997) noted that there is little in published literature about the test-retest reliability of NeuroCom Smart system. Cherng and colleagues (1999) did a reliability study as part of a study of the ability of children with CP to balance in various sensory conditions, but they did the test-retest on the nondisabled control group only. Gabriel and Mu also did a test-retest study on nondisabled children and found that the reliability was good (ICC = 0.90). However, these studies used a force plate and foam pad instead of a Computerized Platform Posturography system, so whether the reliability results are applicable to the Smart EquiTest system is questionable. Liao and colleagues (2001) did a test-retest reliability study of several types of balance tests, including the Smart EquiTest, in children with mild to moderate spastic diplegic CP, and found that only the conditions demonstrating postural stability while focusing on a central target with a fixed support system had good reliability. Tests demonstrating balance while the subject had his or her eyes open with fixed support, eyes closed with fixed support, swayed reference vision and fixed support, eyes open and swayed support, eyes closed and swayed support, and swayed reference vision and swayed support had poor reliability. However, only an intrasession test-retest was performed on the children with cerebral palsy. They did an intersession test on non-disabled children in which they separated the test periods by one week and found no learning effect and high reliability. There is no way to determine whether the poor reliability found for the children with CP is due to their disability or to the fact that they were tested and retested on the same day.

There is little in published literature about Motor Control Tests, and no published studies on the performance of children with cerebral palsy. The MCT is an important test for therapists to use with children with cerebral palsy because it measures response to unexpected platform movements. It has been established that children with cerebral palsy have neuromuscular deficits, and it would be helpful for therapists to be able to measure response to these perturbations so they can design exercises that would better equip the children to function in an unpredictable world. Forssberg and Nashner (1982) studied the response of normal children to a sudden forward or backward movement of the support surface using a movable force platform and surface electromyography (EMG). They found that the latencies of children below 7 ½ years of age were more erratic and slower than the latencies demonstrated by adults in response to the stimulus. There was also a high degree of variability in the children's EMG adjustments among the trials conducted, suggesting that younger children might randomly change the weighting of support surface, vestibular, and visual input when responding to sudden disturbances. No test-retest reliability was done for this study, and no studies addressing the response of children with cerebral palsy to a motor control test were found.

To enable comprehensive balance testing of children with CP, the test-retest reliability of the SOT and MCT must be established. These results will increase confidence in the use of these measures to describe postural control abilities. Since the SOT has been proven reliable in typical children, we hypothesize that these tests will also be reliable in children with cerebral palsy.

MATERIALS AND METHODS

Subjects

Subjects included 8 children with cerebral palsy and 9 typically developing children between the ages of 4 and 19 years (mean age 9.4). Subjects were recruited from The Children's Hospital of Alabama and the Birmingham community for this study. Inclusion criteria included the ability to stand either with or without an assistive device for 15 minutes. Exclusion criteria included any orthopedic impairments that prevented the child from standing.

Instrumentation

The Smart EquiTest system (NeuroCom International Inc., Clackamas, OR 97015) consists of an 18-in. x 18-in. dual force platform surrounded on three sides by a multicolored panel (the visual surround). Both the force platform and the visual surround are sway referenced. Participants wore a safety harness which attached to a bar at the top of the machine to prevent falls in the event that balance was lost completely. The force platform is composed of five load cells: four on the sides which measure vertical forces (ankle strategy) and one in the center which measures shear forces (hip strategy). The force platform uses the relative amounts of pressure on each load cell to detect the center of gravity (COG), shifts of body mass in response to various stimuli (six sensory conditions), and whether the subject is using primarily ankle or hip strategy in order to maintain balance. The computer system generates a graph comparing the responses of the participant to the expected responses of typically developing subjects of the same age and height. The Smart EquiTest has been demonstrated to have good reliability when used to test typically developing children (Liao et al., 2001) and thus the data used to generate the comparisons may be considered accurate.

Procedures

All participants were tested during two separate sessions 7-10 days apart. During the first session, a battery of neuromuscular tests were done to screen for deficits in their neuromuscular, visual, or vestibular systems.

Neuromuscular Tests:

•Gross Range of Motion: The subjects' arms and legs were moved to determine any restrictions in mobility.

•Strength: The subject moved his or her arms and legs against resistance.

•Oculomotor Testing: (1) Visual Pursuit: the subject was asked to visually track a target as the investigator moved it. (2) Saccades: Subjects were asked to move the eyes quickly from one target to another (e.g., from the examiner's nose to the examiner's finger).

•Head Thrust: Subjects were asked to focus on the investigator's nose as the head is turned to one side quickly and at small amplitude. A corrective saccade back to the examiner's nose indicated possible peripheral vestibular dysfunction.

SOT

The subjects' feet were appropriately positioned on the force platform prior to beginning the SOT. Children were allowed to wear shoes and orthotics and to use assistive devices (i.e., walker) as needed during both the SOT and the MCT in order to imitate the child's typical ambulatory situation as closely as possible. Additionally, the children were allowed to rest for as long as necessary any time they expressed fatigue.

They were then asked to stand still under the following six conditions: 1) Eyes open; 2) Eyes closed; 3) Eyes open, sway-referenced visual surround (the panel will move in response to any movement by the subjects); 4) Eyes open, swayed surface (the platform on which the subjects are standing will move); 5) Eyes closed, swayed surface; and 6) Eyes open, swayed surface and sway-referenced visual surround. Three trials of 20 seconds in duration were administered under each condition. A Polaroid snapshot was taken and placed on the visual surround directly in front of the subject during the eyes open tests to give him or her something to look at and encourage cooperation. Children were given a pair of goggles to wear during the eyes closed tests to occlude vision. Data obtained from the Sensory Organization Tests (SOT) included strategy (whether rotation to maintain balance occurred primarily about the ankle or about the hip joint), and equilibrium score (overall balance under the condition). A composite score was also generated that included data from all six conditions.

MCT

The subjects' feet were repositioned as needed. Subjects were asked to stand still and look straight ahead during small, medium, and large forward and backward translations of the platform. Three tests of each condition were performed with a 1.5-2.5 second interval between each individual trial. The children's feet were repositioned as necessary throughout testing. The Motor Control Test measures latency, which is the amount of time between the first movement of the platform and the subjects' initial response.

All subjects underwent a second testing session 7-10 days later during which they repeated the SOT and MCT.

Analysis

The Smart EquiTest generated a variety of scores which were used during analysis. The Equilibrium Score indicated how well the patient's sway remained within the expected angular limits of stability (12.5°). An equilibrium score close to 100 indicated that the subject was stable (swayed little) and a score of zero indicated that the subject lost balance. The strategy score gave information about whether ankle or hip strategy was predominant (see Instrumentation). A score near 0 indicated a heavy reliance of hip strategy and a score near 100 was indicative of the use of ankle strategy.

Since children typically sway more than adults, sensory ratios were calculated.

These ratios enabled examiners to remove the effect of sway during the eyes open, stable surface condition from the results. The overall visual effectiveness (ability to use vision for balance) was calculated by dividing the equilibrium score for condition 4 by the equilibrium score for condition 1, somatosensory effectiveness (ability to use musculoskeletal information and responses for balance) was obtained by dividing the equilibrium score for condition 3 by the equilibrium score for condition 1, and vestibular effectiveness (ability to use information from the inner ear for balance) was determined by dividing the equilibrium score for condition 5 by the equilibrium score for condition 1.

Several children did not complete all tests because they did not want to do the eyes closed condition (n=2) or they were afraid of the sway-referenced conditions (n=3). These children were not included in the analysis or in the number of recruited children reported in this paper.

SPSS Version 14.0 was used for statistical analysis. Descriptive statistics were done to include the means and standard deviations of all outcomes and sensory effectiveness ratios. Reliability of the SOT was analyzed using the intraclass correlation coefficient (ICC) model 3. Reliability was done for the average of all three trials (ICC 3,3) as well as for trial 1 only (ICC 3,1) to determine if three trials were necessary.

The R2 value was reported for any conditions with inadequate variance for the ICC. For this reason, reliability of the MCT was analyzed using R2.

RESULTS

Descriptive data of the subjects with cerebral palsy (n=8) can be found in Table 1. Subjects #8 and #20 were noted to have abnormal smooth pursuit and saccades on the left side, indicating possible damage to the central visual pathways. Subject #8 also had a positive head thrust to the left which could indicate either peripheral vestibular hypofunction or central pathology. All other subjects had a normal oculomotor examination and a negative head thrust. All subjects except subject #20 stood independently for testing. Subject #20 was unable to stand without a posterior rolling walker. The walker was placed on the support surface so that the upper extremities could be used for balance.

Subject #	Age (yrs.)	Diagnosis	*Strength Rt.	*Strength Lt.	** ROM Limitations Rt.	** ROM Limitations Lt.	Orthoses
7	19	R. hemiplegia	3+	5	None	B	None
8	7	Splastic diplegia	3+	3+	B	B	None
10	5	Splastic diplegia	4+	4	GS	None	Yes
11	10	Splastic diplegia	4	3+	H	B	None
16	8	Splastic diplegia	4	3+	B	B	Yes
18	4	R. hemiplegia	3+	4	B	None	Yes
20	5	Quadriplegia	2+	2+	B	B	Yes
22	5	Splastic diplegia	3+	3	B	B	Yes

*Overall Manual Muscle Test
**limitations notest in hamstrings (H), gastoc-soleus complex (GS), or both (B)

Subjects With Cerebral Palsy—Detailed Description

7. 19-year-old with hemiplegia who used no assistive device and no orthoses. This subject was most affected on the right side (strength 3+/5 compared with 5/5 on the left). All the oculomotor and head thrust tests (see below) were normal, and glasses were not worn.

8. 7-year-old with spastic diplegia who used no assistive device and no orthoses. This subject was equally affected on both sides (strength 3+/5). The smooth pursuit and saccades tests were abnormal on the left side and the head thrust test was positive to the left. Glasses were worn.

10. 5-year-old with spastic diplegia who used no assistive device but did use orthoses. This subject was equally affected on both sides (strength 4/5). All oculomotor and head thrust tests were normal and glasses were not worn.

11. 10-year-old with spastic diplegia who used no assistive device or orthoses. This subject was more affected on the right side (strength 3+/5 compared with 4/5 on the left). All oculomotor and head thrust tests were normal and glasses were not worn.

16. 8-year-old with spastic diplegia who used no assistive device but did use orthoses. This subject was equally affected on both sides (strength 3+/5). All oculomotor and head thrust tests were normal and glasses were worn.

18. 4-year-old with hemiplegia who used no assistive device but did use orthoses. The subject was more affected on the right side (strength 3+/5 compared to 4/5 on the left). All oculomotor and head thrust tests were normal and glasses were worn.

20. 5-year-old with quadriplegia who used a walker and orthoses. The subject was equally affected on both sides (strength 3+/5). Visual pursuit and saccades tests were abnormal and the head thrust tests was negative. Glasses were not worn, but this subject had a cochlear implant to correct deafness.

22. 5-year-old with spastic diplegia who did not use an assistive device but did use orthoses. The left side was more affected (strength 3/5 compared with 3+/5 on the right). All oculomotor and head thrust tests were normal and glasses were not worn.

Results indicate that the SOT is very reliable for equilibrium scores for both typically developing children (ICC (3,3) > 0.81) and children with cerebral palsy (ICC (3,3) > 0.89) (tables 1 & 2). The equilibrium results from the subjects who had cerebral palsy did not generate enough variability to allow the ICC to be calculated for conditions 2 and 3. The R2 values calculated for conditions 2 and 3 were 0.25 and 0.24, respectively. Although these values are relatively low, examination of the averages seems to indicate that reliability is, in fact, high (table 2). The inadequate variance and relatively low R2 value is likely due to a limited sample size.

Table 1: SOT Equilibrium Reliability All Subjects (n=17)

Condition	Test 1*	Test 2*	ICC (3,3)
1	87.4	84.5	0.92
2	83.1	82.1	0.82
3	80.8	80.0	0.81
4	62.3	66.1	0.87
5	43.4	45.4	0.93
6	37.0	44.6	0.86

*Equilibrium Score Average of 3 Trials

Table 2: SOT Equilibrium Reliability CP Subjects (n-8)

Condition	Test 1*	Test 2*	ICC (3,3)
1	83.5	79.8	0.93
2	83.1	82.1	Inadequate Variance: R^2=0.24
3	75.9	73.6	Inadequate Variance: R^2=0.25
4	57.4	55.6	0.91
5	39.3	39.1	0.96
6	40.0	44.8	0.89

*Equilibrium Score Average of 3 Trials

A single trial of each condition is not adequate to obtain reliable results (Table 3). When only the first trial of each condition was analyzed, no ICC (3,3) scores were above 0.76 for all subjects and no scores were above 0.72 for the subjects with cerebral palsy only.

The SOT strategy scores showed moderate reliability for typically developing children and poor reliability for children with CP (Tables 4 and 5). The motor control test does not appear to be reliable for children. Investigation of the descriptive data indicated that latencies tended to vary widely from day 1 to day 2, and the R2 indicate that very little of that variation is shared between days (Table 6).

Table 3: SOT Equilibrium Test-Rest Reliability of Trial 1 Only

Condition	ICC (3,1) All Subjects	ICC (3,1) CP Subjects
1	0.69	0.68
2	0.61	0.55
3	0.76	0.71
4	0.61	0.72
5	R^2=0.15	R^2=0.09
6	0.56	0.64

Table 4: SOT Strategy Test-Retest Reliability CP (n=8)

Condition	Test 1*	Test 2*	ICC (3,3) CP Subjects
1	95.4	94.3	0.96
2	78.2	93.6	Negatively correlated
3	92.9	89.6	R^2=0.55
4	85.3	81.2	0.72
5	81.1	73.3	R^2=0.07
6	78.2	83.0	Negatively correlated

Table 5: SOT Strategy Test-Retest Reliability (n=9 typical subjects and 8 CP subjects) Average of 3 Trials

Condition	Test 1*	Test 2*	ICC (3,3) All Subjects
1	96.4	95.2	0.90
2	76.0	94.8	Negatively correlated
3	94.6	93.4	0.72
4	86.6	94.8	0.74
5	81.9	78.9	R^2=0.10
6	76.0	82.7	Negatively correlated

Table 6: MCT Mean Latencies and R^2 Values All Subjects

Platform Motion	Test 1 Latency Left	Test 2 Latency Left	Test 1 Latency Right	Test 2 Latency Right	R^2 (L/R)
Medium Back	140	127	141	121	0.29/0.47
Large Back	135	121	140	127	.001/0.06
Medium Forward	165	152	190	160	0.36/0.18
Large Forward	160	143	165	155	0.31/0.26

CONCLUSIONS

The Sensory Organization Test is reliable for children, and may be used clinically by therapists to discern the sensory systems that may be the cause of balance dysfunction. This will allow the therapist to design exercises to deal with the specific deficits displayed by the child in response to the SOT. Further studies should be done with larger sample sizes to verify these results, but it appears that children with cerebral palsy do not have a specific strategy that they use reliably in a given situation. This may be due to their neuromuscular deficits, but there is also a possibility that they are learning a variety of strategies for maintenance of balance as a result of their physical therapy regimes. Further investigations should be made to determine the cause of the multiple strategies for balance which are apparently chosen somewhat at random by children who have cerebral palsy.

Three trials of each condition must be performed and the results averaged because a single trial is not adequate for reliable results for the SOT. Subjects typically did worst on the first trial of each condition (performance tended to improve once subjects knew what to expect and how to adjust for it), and thus it is not surprising that the first trial alone was not reliable for any of the conditions.

These results suggest that the Motor Control Test may not be reliable for children. This is similar to results obtained by Forssberg and Nashner (1982) suggesting that children younger than 7 would not have reliable responses to a platform perturbation. It is possible that the sample used for this study simply contained too many young children, and that a study which focused on children older than 10 might show that the MCT is reliable for that population.

In conclusion, all of the subjects were able to complete the SOT and the MCT. Subject #20, who used a walker, did not sway on any condition and did not have a lower extremity response to the platform perturbation on the MCT. This suggests that subjects with CP who stand and ambulate with a walker very rarely have to rely on their lower extremities. Although use of a walker provides stability under conflicting sensory situations, the child may become dependent on the walker, not exercising the visual and vestibular systems that will allow motor skill progression and independent walking. Future studies should continue to examine computerized dynamic posturography in more subjects with cerebral palsy.

REFERENCES

- Cambier, D., Cools, A., Danneels, L., and Witvrouw, E. Reference data for 4- and 5-year-old-children on the Balance Master: values and clinical feasibility. Eur.J.Pediatr.2001;160:317-
- Cherng, R. J., Chen, J. J., and Su, F. C. Vestibular system in performance of standing balance of children and young adults under altered sensory conditions.Percept.Mot. Skills.2001;92:1167-1179.
- Cherng, R. J., Su, F. C., Chen, J. J., and Kuan, T. S. Performance of static standing balance in children with spastic diplegic cerebral palsy under altered sensory environments.Am.J.Phys.Med.Rehabil.1999;78:336-343.
- Crenna, P. Spasticity and 'spastic' gait in children with cerebral palsy.Neurosci.Biobehav.Rev.1998;22:571-578.
- Forssberg, H. and Nashner, L. M. Ontogenetic development of postural control in man: adaptation to altered support and visual conditions during stance.J.Neurosci.1982;2:545-552.
- Foudriat, B. A., Di Fabio, R. P., and Anderson, J. H. Sensory organization of balance responses in children 3-6 years of age: a normative study with diagnostic implications. Int.J.Pediatr.Otorhinolaryngol.1993;27:255-271.
- Gabriel, L. S. and Mu, K. Computerized platform posturography for children: test-retest reliability of the sensory test of the VSR System.Phys.Occup.Ther.Pediatr.2002;22:101-117.
- Hirabayashi, S. and Iwasaki, Y. Developmental perspective of sensory organization on postural control.Brain Dev.1995;17:111-113.
- Liao, H. F. and Hwang, A. W. Relations of balance function and gross motor ability for children with cerebral palsy. Percept.Mot.Skills.2003;96:1173-1184.
- Liao, H. F., Jeng, S. F., Lai, J. S., Cheng, C. K., and Hu, M. H. The relation between standing balance and walking function in children with spastic diplegic cerebral palsy.Dev. Med.Child Neurol.1997;39:106-112.
- Liao, H. F., Mao, P. J., and Hwang, A. W. Test-retest reliability of balance tests in children with cerebral palsy.Dev.Med. Child Neurol.2001;43:180-186.
- Lundy-Ekman, Laurie. Somatosensory System. In: Neuroscience: Fundamentals for Rehabilitation. Philadelphia: W.B. Saunders Co.2005a.; 99-122.
- Lundy-Ekman, Laurie. Vestibular and Visual Systems. In: Neuroscience:Fundamentals for Rehabilitation. Philadelphia: W.B. Saunders Company; 2005b.349-381.
- NeuroCom International, Inc. Clinical Integration Seminar Lecture Manual.2005;
- Poblano, A., Ishiwara, K., de Lourdes, Arias M., Garcia-Pedroza, F., Marin, H., and Trujillo, M. Motor control alteration in posturography in learning-disabled children.Arch.Med. Res.2002;33:485-488.
- Portney and Watkins M. Reliability. In: Foundations of Clinical Research: Applications to Practice. New Jersey: Prentice Hall Health; 61-77.
- Rine, R. M., Rubish, K, and Feeney, C. Measurement of Sensory System Effectiveness and Maturational Changes in Postural Control in Young Children.Pediatric Physical Therapy.2005;10:16-22.
- Rose, J., Wolff, D. R., Jones, V. K., Bloch, D. A., Oehlert, J. W., and Gamble, J. G. Postural balance in children with cerebral palsy.Dev.Med.Child Neurol.2002;44:58-63.