Concurrent Validity of the Pediatric Clinical Test of Sensory Interaction for Balance to Quantify Postural Sway and Movement Strategies of Children Aged 7-12 Years

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Objective: *To investigate the concurrent validity of the Pediatric Clinical Test of Sensory Interaction for Balance (P-CTSIB), to quantify anterior-posterior sway and movement strategies using a motion analysis system as the gold standard.*

Material and Method: *Protocol of the six conditions of P-CTSIB was used. For each condition, data were simultaneously collected from the standard measure and a motion analysis system and analyzed using Intraclass Correlation Coefficients and validity indexes.*

Results: *Seventeen children with a mean age of 9.34 years (SD = 1.61) performed the test. For anterior-posterior sway data, highly significant agreements were found between the two measurement systems (ICC (2,1) = 0.945-0.986, p<0.05). Sensitivities of the standard measure to detect immature movement strategy varied from 62.96 to 75.71%, while specificities ranged between 68.12 and 97.22%. Positive and negative predictive values ranged from 46.43 to 94.74%.*

Conclusion: *The standard protocol of P-CTSIB has strong concurrent validity to measure anterior-posterior sway and acceptable levels of validity indexes to detect immature movement strategy, in addition to being a portable and simple clinical tool for objective assessment of standing balance in children.*

Keywords: *Balance, Children, Measurement, Standing, Validity*

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Balance assessment is an important component of the physical therapist's evaluations[1-3]. To identify specific treatment goals for balance, measurements of the ability to maintain balance under different sensory conditions are useful[4,5]. One of the standardized clinical balance assessment tools for children based on sensory organization is the Pediatric Clinical Test of Sensory Interaction for Balance (P-CTSIB)[1,2]. This test is portable and easy to administer. Outcome measures include stance duration, observations of amplitude of sway and movement strategies[1,3,4]. Under this convenient administration, validity of the outcomes is of interest. Using high technology equipment clarifies whether the standard protocol of the P-CTSIB yields the measurement outcomes comparable to the kinematic data obtained from laboratory tests such as motion analysis systems.

The objective of the present study was to explore the concurrent validity of the standard protocol of the P-CTSIB to measure degree of sway and movement strategies using a motion analysis system as the gold standard. Based on the assumption that the standard protocol is a clinical alternative to high technology equipment[3], the hypothesis of the present study was that the children's balance performances obtained from the standard protocol and a motion analysis system would correlate.

Material and Method

The present study used a correlation research design to collect data on balance performance of children. Tests were performed in a motion analysis, systems laboratory.

Seventeen children were recruited after their parents had signed informed consent forms approved by the Mahidol University Institutional Review Board (MU-IRB 2014/015.2301). The volunteer children were recruited from local and special schools in Bangkok

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and perimeter areas. Of the total volunteers, 12 children were typically developing children and five were children with spastic cerebral palsy. The inclusion criteria included age between 7 and 12 years, ability to understand and follow verbal instructions, participation in regular classroom activities, and ability to stand independently for at least 30 seconds. Exclusion criteria included open wound on the foot, hearing or visual problems that could not be fixed with external devices, physical anomalies or joint contracture.

Each child performed six sensory conditions of the P-CTSIB: condition 1) eyes open, standing on the floor; condition 2) eyes closed, standing on the floor; condition 3) eyes open, wearing a visual conflict dome, standing on the floor; condition 4) eyes open, standing on medium density foam; condition 5) eyes closed, standing on medium density foam and condition 6) eyes open, wearing a visual conflict dome, standing on medium density foam[1,4,6]. Children were required to wear a T-shirt and shorts. A head pointer was placed and secured by a strap on the child's head. Six reflective markers were affixed to the top of the head pointer, right acromion process, right greater trochanter, right lateral femoral condyle, right lateral malleolus and right head of 2nd metatarsal[7]. A physical therapist with experience in pediatrics, who achieved high validity in marker placements, was compared with an expert in musculoskeletal physical therapy (Kappa = 0.89-1.00, $p<0.05$), and was responsible for the marker placements on all children. Degree of anterior-posterior sway and movement strategies used to maintain standing balance at 0, 5, 10, 15, 20, 25, and 30 seconds were scored using the standard protocol of the P-CTSIB and a motion analysis system. Degree of sway was recorded in degrees, whereas movement strategy was recorded as either mature (for non-strategy, ankle strategy and hip strategy) or immature (for other strategies) response.

Standard protocol

An examiner with more than 5 years' experience in using the P-CTSIB and with high intra-rater reliability of measuring the P-CTSIB (ICC (2,1) = 0.98, $p<0.05$) was responsible for measuring the degree of sway and movement strategy using the standard protocol. A video camera was set on the right side of the children to record the performance of the children and a backdrop with degree lines was placed on the left side of the children to measure degree of sway. The examiner measured children's performance from the video. The angle that the head pointer moved from the central axis determined the anterior-posterior sway degree[1,4,6,8]. If the head pointer moved backward from the central axis, the degree was recorded in a negative value. The examiner also recorded the movement strategy that each child used to maintain standing balance. The data were recorded as 0 for no strategy, 1 for ankle strategy (movement response from ankle to proximal parts), 2 for hip strategy (movement response from hip to distal parts), and 3 for other strategies including suspensory and stepping strategies[1,4,9,10].

Motion analysis system

A 10-infrared camera VICON Nexus^{TM} motion analysis system (Oxfords Metrics Ltd, Oxford, UK) with sampling rate of 100 Hz was used to capture the three-dimensional trajectory data of the six reflective markers. The motion analysis system was operated by experienced VICON users. Degree of anterior-posterior sway was collected from two reflective markers, i.e., the marker on the top of the head pointer and at the lateral malleolus and calculated from the equation: $\theta = \tan^{-1}(b/c)$, where θ = degree of anterior-posterior sway, b = side opposite θ, c = side adjacent θ. Movement strategy was obtained from five reflective markers on the right acromion process, right greater trochanter, right lateral femoral condyle, right lateral malleolus and right head of second metatarsal. Ankle angle was calculated from the markers at the head of second metatarsal, lateral malleolus and lateral femoral condyle. Knee angle was calculated from the markers at the lateral malleolus, lateral femoral condyle and greater trochanter. Hip angle was calculated from the markers at the lateral femoral condyle, greater trochanter and acromion process. Each angle was calculated using the "law of cosine". In addition, standard error of measurements (SEMs) for ankle, knee and hip angles were calculated to use as the reference of true change at each joint[5]. The angle that changed beyond ± 1 SEM was defined as the true change of the joint. Initial change of joint angle was identified for each sensory condition. No strategy was recorded when no true changes could be observed at any joints. Ankle strategy was recorded when the initial change occurred at the ankle joint. Hip strategy was recorded when the initial change occurred at the hip joint. Other strategies were recorded when the initial changes occurred at the knee or more than one joint. The use of either "hip strategy" or "other strategies" was considered as having immature movement strategy[1,4]. All kinematic data were computed with MATLAB (R2013a) software (Mathworks Inc, Natick, MA).

The statistical analyses were performed using SPSS for windows. A p-value <0.05 was considered statistically significant. Kolmogorov-Smirnov goodness of fit test was used to assess data normality. Intraclass-correlation coefficients ($ICC_{(2,1)}$) were used to assess the levels of agreement between anterior-posterior degree of sway data obtained from the two measuring techniques. Validity indexes calculated for movement strategy data were sensitivity, specificity, positive predictive value and negative predictive value[5]. Definitions and formulas to calculate the validity indexes were followed from Portney L and Watkins M (2000)[5], where test positive was recorded for a child when the tests (either the standard protocol or motion analysis) detected that the child used immature movement strategy to maintain standing balance.

Results

Seventeen children with a mean age of 9.34 years (SD = 1.61) were recruited to the present study. Characteristics of the children classified by types are summarized in Table 1.

Data on degree of sway were normally distributed. The mean, standard deviation and 95% confidence interval values for anterior-posterior degree of sway over the six conditions of P-CTSIB measured by the standard protocol and the motion analysis system are summarized in Table 2. Levels of agreement (ICC) between the two measuring protocols ranged from 0.945 for condition 6 to 0.986 for condition 2 (Table 2).

Percentages of immature movement strategy found in each condition of the P-CTSIB as identified by the standard protocol and the motion analysis system are summarized in Table 3. Validity indexes including sensitivity, specificity, positive predictive value and negative predictive value for the standard protocol to identify immature movement strategy using the outcomes from the motion analysis system as a gold standard are also reported in Table 3.

Discussion

The P-CTSIB was developed to provide a portable, clinical alternative to platform posturography[1,6]. It has been proved useful for discriminative purpose but the evaluative purpose required further investigations[8]. The original version of P-CTSIB measured four balance variables including stance duration, amount of sway, nominal sway categories and movement strategy[1,6,11,12].

Stance duration was the amount of time that children could stand in a feet-together position until they made gross postural adjustment or to a maximum of 30 seconds[6]. To study all balance variables

Table 1. Mean (standard deviation) values of general demographic data of children (n = 17)

Children	Age (year)	Weight (kg)	Height (cm)	Body Mass Index
Children with typical development (n = 12)	8.94 (1.41)	26.77 (4.99)	126.58 (6.50)	16.58 (2.03)
Children with cerebral palsy (n = 5)	10.28 (1.82)	29.21 (11.38)	128.80 (7.26)	17.48 (6.45)

Table 2. Results of the anterior-posterior degree of sway for six conditions of P-CTSIB measured by the standard protocol and the motion analysis system

P-CTSIB conditions	Standard protocol			Motion analysis system			ICC	*p*-value
	Mean	SD	95% CI	Mean	SD	95% CI		
1	1.78	0.31	1.50, 2.07	2.16	0.21	1.97, 2.36	0.966	<0.001
2	1.47	0.32	1.18,1.77	2.66	0.28	2.40, 2.92	0.986	<0.001
3	-0.37	0.24	-0.59, -0.15	0.94	0.26	0.70, 1.18	0.963	<0.001
4	2.14	0.35	1.82, 2.46	2.87	0.37	2.52, 3.20	0.977	<0.001
5	2.74	0.61	2.17, 3.30	3.36	0.72	2.69, 4.03	0.971	<0.001
6	1.76	0.50	1.30, 2.23	2.50	0.19	2.32, 2.68	0.945	<0.001

P-CTSIB condition 1: eyes open, stand on the floor, condition 2: eyes closed, stand on the floor, condition 3: eyes open, wear a visual conflict dome, stand on the floor, condition 4: eyes open, stand on medium density foam, condition 5: eyes closed, stand on medium density foam, and condition 6: eyes open, wear a visual conflict dome, stand on medium density foam

Table 3. Validity indexes of the standard measure of P-CTSIB to identify immature movement strategy compared with the motion analysis system

P-CTSIB conditions	% immature movement strategy		Sensitivity (%)	Specificity (%)	Predictive value (%)	
	Standard	VICON			Positive	Negative
1	31.09	39.50	74.47	97.22	94.59	85.37
2	47.90	58.82	75.71	91.84	92.98	72.58
3	45.38	62.18	67.57	91.11	92.59	63.08
4	56.30	69.75	74.70	86.11	92.54	59.62
5	63.87	78.15	77.42	84.62	94.74	51.16
6	52.94	68.07	62.96	68.42	80.95	46.43

P-CTSIB condition 1 = eyes open, stand on the floor; condition 2 = eyes closed, stand on the floor; condition 3 = eyes open, wear a visual conflict dome, stand on the floor; condition 4 = eyes open, stand on medium density foam; condition 5 = eyes closed, stand on medium density foam; condition 6: eyes open, wear a visual conflict dome, stand on medium density foam

throughout the 30 second-period of assessment, the present study included only children who could maintain the stance for at least 30 seconds. Thus, all children in the present study could reach the maximum score for stance duration and this item was not used.

Amount of sway was recorded by an observational measurement of anterior-posterior sway[8,13-16]. Angle that the head pointer pointed to the backdrop with degree lines was recorded as the anterior-posterior degree of sway[1,6,11,12]. The anterior-posterior sway as measured by this method achieved high agreement levels when compared with kinematic data from the motion analysis system (Table 2). A previous study used the P-CTSIB to measure sway in children aged 4 to 5 years and reported the mean anterior-posterior sway between 1 and 7 degrees[12], while the sway indexes for young adults were 0.21 to 2.20[17]. The present study measured the sway degree in children aged 7 to 12 years and found that the data were between the ranges reported for pre-schoolers and young adults (Table 2). When assessing the levels of agreement between the standard protocol and the kinematic data obtained from the motion analysis system, the standard protocol reached strong levels of agreement for all conditions of the P-CTSIB (Table 2). These findings are consistent with the hypothesis that the two methods measured the same performance concurrently[5]. Few variations could be found due to the higher precision of the motion analysis system compared with human judgment. Therefore, if the two methods have concurrent validity in measuring the same construct, then their agreement should be high. In addition, the examiner measured the degree of sway by video; therefore, errors from interfering children during testing did not occur. These may be factors for achieving high levels of agreement of the standard protocol to identify anterior-posterior degree of sway of the P-CTSIB. Further validity studies of real time scoring may be needed if researchers propose to score the P-CTSIB in the real time situation.

The standard protocol of the P-CTSIB reported "nominal sway categories" including 1) inability to assume standing position, 2) a fall during the test and 3) inability to maintain standing balance longer than 3 seconds[6]. This recorded item was intended to identify those with incomplete balance data. The score of 3 defined children who could not be scored for amount of sway because sway is impossible to measure accurately if the child could not maintain a stance for longer than 3 seconds. None of the children in the present study was reported in any of the categories because they could maintain stance for longer than 30 seconds. Thus, this item was not used in the present study.

Movement strategies that the children used to maintain stance in each condition of the P-CTSIB were identified according to published protocol[1,4,10]. To compare the standard protocol with the kinematic data, the identified strategies were further recoded as either mature or immature movement strategy[13,18]. The validity indices were calculated to predict the immature movement strategy using the standard protocol of the P-CTSIB and set the kinematic results of motion analysis system as the gold standard. It was found that children tended to use more immature movement strategies in more difficult conditions, especially conditions 5 and 6. This finding was consistent with the results reported in typical children aged 7-15 years[10]. Percentages of immature movement strategy as identified by the motion analysis system were higher than the standard protocol in all conditions. However, the differences were not statistically significant. These higher identification rates may be due to the higher precision of the kinematic data obtained from the motion analysis system compared with human judgment. When considering the validity indexes, the standard protocol obtained higher specificity than sensitivity in all conditions (Table 3). Thus, the accuracy to identify the children with true mature movement strategies was higher than the accuracy to identify those with immature movement strategies. Negative predictive values were also higher than positive predictive values in all conditions. The results indicated the higher probability to correctly identify children with mature movement strategies than those with immature movement strategies. These findings may have resulted because ankle and hip strategies were more consistent in patterns than the immature movement strategies. As the participants in the present study consisted of those with typical and abnormal developments, the immature movement strategies may include immature and abnormal strategies. Therefore, it was more difficult to identify immature strategies than mature strategies. Care should be taken when using the standard protocol to identify immature movement strategies in the clinic. From these findings, the standard protocol has strong validity in identifying mature movement strategies in clinical settings.

Conclusion

Assessments of balance control in developing children are important. In clinical settings without high technology equipment or in community services, the P-CTSIB has gained popularity being portable and easy to administer[9]. The present study proved that the standard method of measuring the anterior-posterior degree of sway and identifying immature movement strategies of high function children are acceptable and comparable with 3-dimensional kinematic data obtained from a motion analysis system. These validity indexes could only be applied to settings that score the P-CTSIB from video. Further validity studies on other types of children and scoring the P-CTSIB in real time situations are suggested.

What is already known on this topic?

The six sensory conditions of the P-CTSIB are a well-accepted clinical tool to assess balance in children.

What this study adds?

Using the motion analysis system as the gold standard, the validity indexes of standard protocol were acceptable to quantify the anterior-posterior degree of sway and identify movement strategy under the six sensory conditions of the P-CTSIB.

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Potential conflicts of interest

None.

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ความเที่ยงตรงตามสภาพของการทดสอบพีซีทีเอสไอบีในการวัดองศาการเซและกลวิธีการเคลื่อนไหวในเด็กอายุ 7 ถึง 12 ปี

ระวีวรรณ เล็กสกุลไชย, สุพรรณิการ์ ขัดลิ

วัตถุประสงค์: *เพื่อศึกษาความเที่ยงตรงตามสภาพของการทดสอบพีซีทีเอสไอบีในการวัดองศาการเซในทิศหน้า หลัง และกลวิธีการเคลื่อนไหวโดยใช้ระบบการวิเคราะห์การเคลื่อนไหวเป็นเกณฑ์มาตรฐาน*

วัสดุและวิธีการ: *ใช้วิธีการวัด 6 สภาวะทดสอบของพีซีทีเอสไอบี ในแต่ละสภาวะทดสอบข้อมูลการทรงตัวของเด็กถูกบันทึกพร้อมกันด้วยวิธีการให้คะแนนมาตรฐาน และระบบการวิเคราะห์การเคลื่อนไหว และวิเคราะห์ข้อมูลทางสถิติด้วย Intraclass Correlation Coefficient และ ดัชนีความแม่นยำ*

ผลการศึกษา: *เด็กจำนวน 17 คน อายุเฉลี่ย 9.34 ปี (ค่าเบี่ยงเบนมาตรฐาน = 1.61) ได้รับการทดสอบ สำหรับข้อมูลการเซในทิศหน้า หลัง พบความสัมพันธ์ในระดับสูง ระหว่างวิธีการวัดทั้งสองแบบ (ICC = 0.945-0.986, p<0.005) ความไวของวิธีการให้คะแนนแบบมาตรฐานในการระบุกลวิธีการเคลื่อนไหวที่ไม่พัฒนาเต็มที่มีค่าตั้งแต่ 62.96 ถึง 75.71 เปอร์เซ็นต์ ในขณะที่ความจำเพาะมีค่าระหว่าง 68.12 และ 97.22 เปอร์เซ็นต์ ค่าการทำนายเชิงบวก และค่าการทำนายเชิงลบมีค่าตั้งแต่ 46.43 ถึง 94.74 เปอร์เซ็นต์*

สรุป: *วิธีการให้คะแนนแบบมาตรฐานของพีซีทีเอสไอบีในการวัดองศาการเซในทิศหน้า หลัง มีความเที่ยงตรงตามสภาพในระดับสูง และมีค่าดัชนีความแม่นยำในการระบุกลวิธีการเคลื่อนไหวที่ไม่พัฒนาเต็มที่อยู่ในระดับที่ยอมรับได้ อีกทั้งยังใช้ง่ายและสามารถนำไปใช้ได้ในทางคลินิก จึงสามารถใช้เพื่อวัดข้อมูลเชิงปริมาณของทรงตัวในท่ายืนของเด็กได้*
