Article

CLINICAL REHABILITATION

Clinical Rehabilitation
26(7) 664–671

DOI: 10.1177/0269215511426889
cre.sagepub.com
SAGE

Reliability and validity of the five-repetition sit-to-stand test for children with cerebral palsy

Tze-Hsuan Wang[1], Hua-Fang Liao[1] and Yi-Chun Peng[2]

Abstract

Objective: To investigate the psychometric properties of the five-repetition sit-to-stand test, a functional strength test, in children with spastic diplegia.
Design: Methodology study.
Settings: Hospital, laboratory or home.
Participants: In total, 108 children with spastic diplegia and 62 with typical development aged from five to 12 years were tested. For test-retest reliability, 22 children with spastic diplegia were tested twice within one week.
Interventions: Not applicable.
Main measures: The five-repetition sit-to-stand test measures time needed to complete five consecutive sit-to-stand cycles as quickly as possible. The higher the rate of five-repetition sit-to-stand (repetitions per second), the more strength a person has.
Results: The intraclass correlation coefficients of intra-session reliability and test-retest reliability were 0.95 and 0.99 respectively. The minimal detectable difference was 0.06 rep/sec. The convergent validity of the five-repetition sit-to-stand test was supported by significant correlation with one-repetition maximum of the loaded sit-to-stand test, isometric muscle strength, scores of Gross Motor Function Measure, and gait function (*r* or *rho* = 0.40–0.78). For known group validity, children with typical development and children classified as Gross Motor Function Classification System level I performed higher rates of five-repetition sit-to-stand than children classified as level II, and children classified as level II performed higher rates than level III.
Conclusion: The five-repetition sit-to-stand test was a reliable and valid test to measure functional muscle strength in children with spastic diplegia in clinics.

Keywords

Cerebral palsy, sit-to-stand, reliability, validity, muscle strength

Received: 11th April 2011; accepted: 24th September 2011

[1]School and Graduate Institute of Physical Therapy, College of Medicine, National Taiwan University, Taiwan
[2]Department of Physical Medicine and Rehabilitation, Taipei City Hospital, Taiwan

Corresponding author:
Hua-Fang Liao, School and Graduate Institute of Physical Therapy, College of Medicine, National Taiwan University, 3rd Floor, 17, Xuzhou Rd, Taipei 100, Taiwan, Republic of China
Email: hfliao@ntu.edu.tw

Introduction

Children with cerebral palsy have different degrees of limitation in motor function associated with muscle weakness.[1] Recently, muscle-strengthening exercise has been proven to be beneficial for such children and is considered essential in an intervention programme,[2,3] so measuring muscle strength quantitatively for this population is important. In clinical settings, the functional strength test, which measures a specific functional activity by time, is considered more convenient than hand-held dynamometric tests, achieving more precise numerical results than manual muscle testing.

Standing up from a chair is an important motor skill and has been considered a rehabilitation training protocol for people with motor impairment.[4-7] The timed sit-to-stand test was used to measure lower extremity muscle strength by recording the time needed for three, five or 10 sit-to-stand cycles.[8-11] The five-repetition sit-to-stand test was introduced as an outcome variable in older adults,[12] people with chronic stroke,[7] and people with knee osteoarthritis.[13] For children with spastic diplegia who can ambulate independently or with an assistive device, the five-repetition sit-to-stand test may be an appropriate method to assess functional strength clinically in view of both difficulty of the test and precision of the result. However, as the psychometric properties of this test have not been reported in children with cerebral palsy, comparative data collected from children with typical development were needed.

The main purpose of this study was to examine the reliability and validity of the five-repetition sit-to-stand test in children with spastic diplegia, including:

- the intra-session and test-retest reliabilities, standard error of measurement, and minimal detectable difference;
- the convergent validity with other strength tests (loaded sit-to-stand test, isometric muscle strength) and functional mobility measures (Gross Motor Function Measure, walking speed, and physiological cost index,);
- the known group validity among children with typical development and children with spastic diplegia, who were further classified by their mobility function as Gross Motor Function Classification System (GMFCS) level I, II and III.[14]

Methods

Participants

We retrospectively reviewed data collected for studies on sit-to-stand performance and a functional strengthening programme which contained the five-repetition sit-to-stand test.[6,15-18] A total of 108 children with spastic diplegia (65 boys, 43 girls) and 62 children with typical development (35 boys, 27 girls) were recruited (Table 1). The inclusion criteria for children with spastic diplegia were:

- age between 5.0 and 12.9 years;
- GMFCS levels I to III;
- ability to stand up from a chair independently;
- ability to follow instructions.

The exclusion criteria were pain, severe lower limb deformity, or having undergone lower extremity musculotendinous surgery or botulinum toxin injection in the past six months. For children with typical development, the inclusion criteria were aged between 5.0 and 12.9 years and free of neuromuscular, orthopaedic and cardiovascular diseases.

Table 1. Demographic data of children with spastic diplegia and children with typical development

	Spastic diplegia (*n*=108)	Typical development (*n*=62)
Boys:girls, n	65:43	35:27
Age, y	8.1±1.8	8.7±1.6
Body weight, kg	24.5±7.2	31.3±7.1
Body height, cm	121.0±10.4	132.8±10.8
GMFCS, *n* (I/II/III)	53/43/12	NA

GMFCS, Gross Motor Function Classification System; NA, not applicable.

Table 2. Reliabilities of the five-repetition sit-to-stand test for children with spastic diplegia

	Rate (mean±SD, repetitions/second)			ICC (95% CI)	SEM	MDD
	Trial 1	Trial 2	Trial 3			
Intra-session reliability (*n*=108)	0.42±0.19	0.44±0.19	0.45±0.20	0.95* (0.93–0.96)		
Test-retest reliability (*n*=22)	Day 1	Day 2				
(a) Using the average of three trials	0.31±0.22	0.33±0.23	-	0.99* (0.97–0.99)	0.02	0.06
(b) Using the first trial only	0.29±0.22	0.32±0.22	-	0.97* (0.92–0.99)	0.04	0.11

*P<0.001; CI, confidence interval; ICC, intraclass correlation coefficient; MDD, minimal detectable difference; SEM, standard error of measurement.

Written informed consent was obtained from parents and protocols approved by the hospital Research Ethics Committee.

Procedures

Data collection was conducted in hospitals, laboratories or at home by five trained assessors. Before assessment, children were informed about the procedure and underwent a 10-minute warm-up, including active and passive muscle stretching, sit-to-stand and walking. Children with spastic diplegia were assessed on walking speed and physiological cost index[19] first, followed by the Gross Motor Function Measure.[20,21] After a 10-minute rest, they performed the five-repetition sit-to-stand test and the loaded sit-to-stand test.[6] The isometric muscle strength of a maximum nine muscle groups were collected on a different day. The protocol varied slightly between participants because some variables were collected only for certain groups of children (Tables 2 and 3). For intra-rater test-retest reliability, 22 children with spastic diplegia received five-repetition sit-to-stand tests on two separate days within one week.

Measures

5-repetition sit-to-stand test. This test measured the time required to complete five consecutive sit-to-stand-to-sit cycles as quickly as possible timed using a stopwatch. Its reliability and validity have been demonstrated in geriatric populations.[22-24] A height adjustable chair with no arm rest was used. A rope was set at the level of body height to insure full standing position. Children were tested barefoot on a firm mat. We standardized the starting position with hip flexed at 90° and knee flexed at 105°. The instruction was standardized as 'Fold your arms across the chest. Stand up and sit down as quickly as possible for 5 times. Touch the rope with your head when standing up. The test will be finished when you return to the seated position the fifth time. Continue the sit-to-stand movement till I ask you to stop. If you try but cannot stand up, just let me know. Ready, go!'

Before testing, children practised the sit-to-stand movement three times. Timing began when the trunk-initiated flexion and stopped when the buttocks touched the seat for the fifth time. Children performed the test for three trials with a two-minute rest between trials. It took about 10 minutes to complete the test. The rate of each trial (repetition per second, rep/sec) was obtained from five divided by time and a zero value was assigned to a failure or incompletion trial.[25] Finally, the average rate of three trials was calculated.

Loaded sit-to-stand test. This functional strength test was used to measure the one-repetition maximum of sit-to-stand, which is the maximal load a child is capable of carrying in a body vest while standing up once.[6] It was proven to be reliable, valid and responsive (testing procedure described elsewhere).[6,17,6] In brief, the test began with an initial load equal to 30% of the body weight and progressed based on the performance of previous trials under careful supervision and protection. The normalized one-repetition maximum by body weight was used for statistical analyses.

Muscle strength. Isometric muscle strength of the lower limb was tested by 'make test' with a hand-held dynamometer (Nicholas Manual Muscle Tester Model 01160, Lafayette Instrument Co, IN, USA). Test-retest reliabilities were acceptable in children with cerebral palsy.[27] The strength of each muscle group was evaluated in a random order according to the standardized testing positions described in the study by Hwang *et al*.[27] For each muscle group, bilateral strength was tested three times alternatively. The mean values of the average forces were normalized by body weight.

The trunk extensors strength test was modified from the Biering-Sørensen's study.[28] Initially, children lay prone with their pelvis and legs fixed on a 5-cm height mat and upper body (above iliac crest) resting on the floor. Then, they were asked to assume and maintain an airplane position as long as possible with upper body lifted and arms opened. The duration the child could hold the upper body horizontally without touching the floor was measured using a stopwatch for three trials. The average time (sec) was regarded as the trunk extensor strength.

Gross Motor Function Measure. The Gross Motor Function Measure (GMFM-88) has a high level of validity and reliability in children with cerebral palsy.[20,21] The percentage scores of dimension D (standing, 13 items) and dimension E (walking, running and jumping, 24 items) (range 0–100%) were chosen because they represented the capacities of goal activities for most children with spastic diplegia.

Self-selected walking speed and physiological cost index. Walking speed was tested in a 15-m long walkway. Participants were instructed to walk at their comfortable speed for three trials and the average speed (m/min) measured over the middle 10 m was calculated. The test has high test-retest reliability for children with cerebral palsy.[17]

The physiological cost index has acceptable reliabilities and validity for children with cerebral palsy.[17,19,29] Participants were asked to rest for five minutes and then walk at the self-selected speed for seven minutes. Heart rate was measured every 15 seconds by a heart rate monitor (Polar Electro Oy, Finland) during the last three minutes of resting and the last four minutes of walking. The physiological cost index (beats/m) was calculated by dividing the increment of heart rate during walking by walking speed, and higher values represent less energy efficiency.

Statistical analysis

Reliabilities of five-repetition sit-to-stand were assessed by intraclass correlation coefficient (ICC). The model (3,1) was selected for examining intrasession reliability of the three trials on the first day. For test-retest reliability, a model (3,3) was used to examine the results using the average rates of three trials on two separate testing days. In addition, a model (3,1) was used to examine the results using only the first trial of two separate testing days in order to evaluate the possibility of performing only one trial in clinical settings. For the test-retest data, the Bland–Altman plots were used to examine the presence of systematic errors across the range of measurements.[30] The standard error of measurement, which is an estimate of error to use in interpreting an individual's test score, was calculated as 'standard deviation * √(1-ICC)'. The minimal detectable difference for a 95% confidence interval was expressed as '1.96 * √2 * (standard error of measurement)'.[30] We used Pearson or Spearman correlation analysis to evaluate the convergent validity of the five-repetition sit-to-stand test with other criterion measures according to the Shapiro–Wilks normality test. For known-groups validity, we used the Kruskal–Wallis ANOVA to examine differences among children with typical development and children with spastic diplegia classified as GMFCS level I, II and III. Post-hoc pairwise comparisons were conducted by using the Mann–Whitney *U* test with Bonferroni correction. We used SPSS (Version 13.0, SPSS Inc, IL, USA) for data analysis. The level of significance was set at 0.05 (two-tailed).

Results

The demographic data for both groups are summarized in Table 1. The mean rates of five-repetition

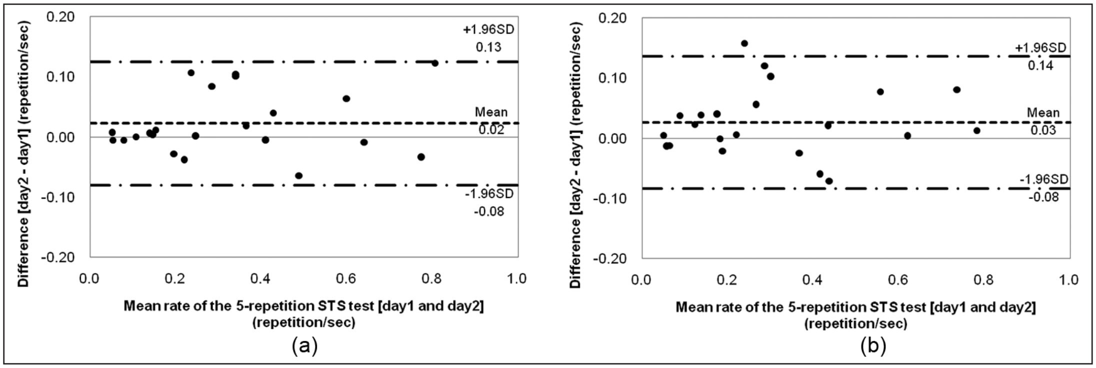

Figure 1. Bland–Altman plot for test-retest reliability of the five-repetition sit-to-stand test in children with spastic diplegia. (a) Using the average rate of three trials; (b) using the rate of the first trial.

sit-to-stand test were 0.44±0.19 rep/sec in the spastic diplegia group and 0.57±0.09 rep/sec in the typical development group.

The reliabilities of the five-repetition sit-to-stand test are shown in Table 2. The ICC values of intra-session reliability and test-retest reliabilities were all above 0.90. No systematic errors were observed by the Bland–Altman plots for test-retest data (Figure 1). The ICC of test-retest reliability was slightly smaller while using only the first trial of two separate days (ICC=0.97) than using the average of three trials (ICC=0.99). Therefore, the minimal detectable difference was larger while using only the first trial of two separate days (0.11 rep/sec) than using the average of 3 trials (0.06 rep/sec).

The convergent validity and mean values of all criterion tests are shown in Table 3. For children with spastic diplegia, the rate of five-repetition sit-to-stand was significantly correlated with all criteria tests except for hip adductors (r=0.30, P=0.19).

For known group validity, there were significant differences in the rates of five-repetition sit-to-stand across children with typical development and the three mobility levels for children with spastic diplegia ($H(3)$ = 56.2, P<0.001, Table 4). The post-hoc test revealed that there were significant differences between GMFCS levels I and II (U=510, P<0.001) and between levels II and III (U=88, P<0.001). However, there was no significant difference between the typical development group and GMFCS level I (U=1493, P=0.40).

Table 3. Convergent validity of the five-repetition sit-to-stand test and mean values of all criterion tests in children with spastic diplegia

	n	mean±SD	*r (rho)*
1-RM of LSTS‡	91	0.47± 0.21	0.59†
Isometric muscle strength			
hip flexors‡	18	0.27±0.08	0.78†
hip extensors‡	18	0.23±0.13	0.68*
hip abductors‡	18	0.27±0.09	0.76†
hip adductors‡	18	0.29±0.08	0.30
knee flexors‡	40	0.18±0.08	0.50†
knee extensors‡	40	0.31±0.11	0.45*
ankle dorsiflexors‡	18	0.09±0.06	0.57*
ankle plantar flexors‡	18	0.46±0.12	0.68*
trunk extensors (sec)	41	33.7±37.7	(0.43)*
Functional measures			
GMFM-D (%)	64	81.8±13.1	(0.65)†
GMFM-E (%)	64	68.9±21.1	(0.75)†
Walking speed (m/min)	45	57.2±15.0	0.41*
PCI (beats/m)	45	1.0±0.5	(-0.40)*

*P<0.05; †P<0.001, correlation coefficients by Pearson (r) or Spearman (*rho*) correlation analysis; ‡ values were normalized by body weight. 1-RM, 1-repetition maximum; GMFM, Gross Motor Function Measure; LSTS, loaded sit-to-stand test; PCI, physiological cost index.

Discussion

In the current study, the reliability and validity of five-repetition sit-to-stand test were first examined for children with spastic diplegia. The five-repetition

Table 4. Known group validity of the five-repetition sit-to-stand test

	Rate (repetitions/second)	
	Mean±SD	Median (25th–75th percentile)
Typical development (*n*=62)	0.57±0.09	0.54 (0.52–0.60)*
GMFCS level I (*n*=53)	0.55±0.14	0.55 (0.44–0.64)
GMFCS level II (*n*=43)	0.38±0.16	0.37 (0.26–0.54)
GMFCS level III (*n*=12)	0.19±0.12	0.17 (0.08–0.26)

*Typical development ~ I > II > III, Kruskal-Wallis ANOVA followed by post hoc Mann–Whitney *U* tests, adjusted for multiple comparisons with Bonferroni's correction. GMFCS, Gross Motor Function Classification System.

sit-to-stand test had good reliability and correlated with the isometric muscle strength and functional mobility measures, while the rate of the five-repetition sit-to-stand was significantly different among children with different GMFCS levels.

The ICC value of test-retest reliability while using the average of three trials was 0.99, which proved that the five-repetition sit-to-stand test had good reliability. The same result was also found in the stroke patients.[31] The standard error of measurement and minimal detectable difference were calculated, and the latter provided a reference value to indicate a true change between the start and the end of an intervention programme with a 95% confidence level. It means that if a child with spastic diplegia completes the five-repetition sit-to-stand for 15 seconds (0.33 rep/sec) before an intervention, they have to shorten the duration to 12.8 seconds (0.39 rep/sec) to meet the real change criterion.

Since the intra-session reliability was good, it seemed reasonable using only one trial of the five-repetition sit-to-stand test in clinical settings. The ICC value of test-retest reliability using only the first trial was 0.97, similar to previous studies reporting ICCs from 0.81 to 0.92 in adults.[22-24] From the above results, it appears that it may be appropriate to test only one trial in clinics with limited time to perform this assessment.

For the convergent validity, the finding showed that the rate of five-repetitions of sit-to-stand correlated moderately with the normalized one-repetition maximum of sit-to-stand, in accordance with our hypothesis. The moderate correlation may be due to more demand on movement speed in the five-repetition sit-to-stand test. In addition, we examined the relationships between five-repetition sit-to-stand test and age, body weight, and height in both children with spastic diplegia and children with typical development. No influence of these growth-related variables was found on the five-repetition sit-to-stand test.

The results of strong relationship between single muscle strength and the five-repetition sit-to-stand test were partly in agreement with previous findings in older people and stroke patients.[24,31,32] In the current study, we found that for children with spastic diplegia, the rate of five-repetition sit-to-stand not only correlated with the strength of primary lower extremity extensors, but also with the strength of trunk extensors, hip flexors, hip abductors, knee flexors, and ankle dorsiflexors as well. During the extension phase of sit-to-stand, the trunk extensor muscles act concentrically to extend the trunk to reach an upright standing position,[33] which explains the significant correlation between the rate of five-repetition sit-to-stand and trunk extensor strength.

In the current study, we demonstrated that the five-repetition sit-to-stand test had moderate to high correlations with the scores of Gross Motor Function Measure and gait speed. Similar results were found in previous studies which showed correlations between single-joint muscle strength and functional measures.[1,34,35] The negative correlation between the rate of five-repetition sit-to-stand and physiological cost index was also similar to previous studies.[35,36]

The mean rate of the five-repetition sit-to-stand was significantly different among children with different severities. Children who were classified as GMFCS level I showed a rate of five-repetition sit-to-stand that was close to children with typical development. The result was consistent with previous findings that only the strength of children at level II and III were below the reference values.[37] In the current study, the rates of five-repetition sit-to-stand in the typical development and level I group were almost higher than 0.50 rep/sec, which was equal to spending 10 seconds to complete five repetitions of sit-to-stand. The result was similar to the cut-off found between young people and the healthy elderly[31] and between adults with and without balance disorders.[38]

Limitations in our study are twofold: firstly, most of the participants in this study were children with mild spastic diplegia so results may not be generalized to all children with cerebral palsy; secondly, the rate of five-repetition sit-to-stand is not only influenced by muscle strength but by other factors, for example sensation, motor control ability and psychological status.[24] However, these factors might not influence the main results of this study.

In conclusion, the five-repetition sit-to-stand test could be used to assess functional muscle strength of the lower limb for children with spastic diplegia. The test had good reliability and correlated with functional performance. In the future, its responsiveness should be investigated.

Clinical messages

- The five-repetition sit-to-stand test showed good reliability in children with spastic diplegia.
- The validity of the five-repetition sit-to-stand test was supported by significant correlations with other strength and mobility measures.
- The five-repetition sit-to-stand test might be useful for evaluating muscle weakness and its change after intervention.

Authors' note

This paper was presented in part at the 10th International Congress of the Asian Confederation for Physical Therapy, August 29, 2008, Chiba, Japan.

Acknowledgements

The authors would like to thank associate professor Jiu-Jeng Lin in the Graduate Institute of Physical Therapy, National Taiwan University for advising on statistical analysis, and the children and families who participated in this study. The authors would also like to thank physical therapists Wei-Pin Huang, Ying-Chi Liu, Shu-Mei Gan, Chin-Chih Liu and Yuh-Ting Lin for helping with the data collection.

Conflict of interest

The authors declare that there is no conflict of interest.

Funding

This work was supported by the National Science Council, Taiwan (grant number NSC90-2314-B-002-315, NSC 92-2314-B-002-141, NSC 98-2314-B-002-011-MY3).

References

1 Ross SA, Engsberg JR. Relationships between spasticity, strength, gait, and the GMFM-66 in persons with spastic diplegia cerebral palsy. *Arch Phys Med Rehabil* 2007; 88: 1114–20.

2 Blundell SW, Shepherd RB, Dean CM, Adams RD, Cahill BM. Functional strength training in cerebral palsy: a pilot study of a group circuit training class for children aged 4-8 years. *Clin Rehabil* 2003; 17: 48–57.

3 Dodd KJ, Taylor NF, Graham HK. A randomized clinical trial of strength training in young people with cerebral palsy. *Dev Med Child Neurol* 2003; 45: 652–7.

4 Britton E, Harris N, Turton A. An exploratory randomized controlled trial of assisted practice for improving sit-to-stand in stroke patients in the hospital setting. *Clin Rehabil* 2008; 22: 458–68.

5 Katz-Leurer M, Rotem H, Keren O, Meyer S. The effects of a 'home-based' task-oriented exercise programme on motor and balance performance in children with spastic cerebral palsy and severe traumatic brain injury. *Clin Rehabil* 2009; 23: 714–24.

6 Liao HF, Liu YC, Liu WY, Lin YT. Effectiveness of loaded sit-to-stand resistance exercise for children with mild spastic diplegia: a randomized clinical trial. *Arch Phys Med Rehabil* 2007; 88: 25–31.

7 Sherrington C, Pamphlett PI, Jacka JA *et al*. Group exercise can improve participants' mobility in an outpatient rehabilitation setting: a randomized controlled trial. *Clin Rehabil* 2008; 22: 493–502.

8 Csuka M, McCarty DJ. Simple method for measurement of lower extremity muscle strength. *Am J Med* 1985; 78: 77–81.

9 Finch E, Stratford P, Brooks D, Mayo N. *Physical rehabilitation outcome measures: a guide to enhanced clinical decision-making*, 2nd edn. Toronto: Canadian Physiotherapy Association, 2002.

10 Guralnik JM, Simonsick EM, Ferrucci L *et al*. A short physical performance battery assessing lower extremity function: association with self-reported disability and prediction of mortality and nursing home admission. *J Gerontol* 1994; 49: M85–94.

11 Taylor NF, Dodd KJ, Larkin H. Adults with cerebral palsy benefit from participating in a strength training programme at a community gymnasium. *Disabil Rehabil* 2004; 26: 1128–34.

12 Schlicht J, Camaione DN, Owen SV. Effect of intense strength training on standing balance, walking speed, and sit-to-stand performance in older adults. *J Gerontol A Biol Sci Med Sci* 2001; 56: M281–6.

13 Sled EA, Khoja L, Deluzio KJ, Olney SJ, Culham EG. Effect of a home program of hip abductor exercises on knee joint loading, strength, function, and pain in people with knee osteoarthritis: a clinical trial. *Phys Ther* 2010; 90: 895–904.

14 Palisano R, Rosenbaum P, Walter S *et al*. Development and reliability of a system to classify gross motor function in children with cerebral palsy. *Dev Med Child Neurol* 1997; 39: 214–23.

15 Liao HF, Hwang WB, Hsu AT, Wong AMK. The relations between sit-to-stand functional muscle strength and gross motor function, muscle strength of lower extremities in children with spastic diplegia. *Formos J Phys Ther* 2005; 30: 207–16.

16 Liao HF, Liu YC, Liu CC. The relations between body composition and muscle strength of lower extremities in independent walkers with spastic diplegic cerebral palsy and non-disabled children. *Formos J Phys Ther* 2002; 27: 273–82.

17 Liu CC, Liao HF, Lin KH. The relations between the sit-to-stand functional muscle strength and walking capacity in children with mild spastic diplegia. *Formos J Phys Ther* 2004; 29: 176–83.

18 Peng YC, Lu TW, Wang TH *et al*. Immediate effects of therapeutic music on loaded sit-to-stand movement in children with spastic diplegia. *Gait Posture* 2011; 33: 274–8.

19 Raja K, Joseph B, Benjamin S, Minocha V, Rana B. Physiological cost index in cerebral palsy: its role in evaluating the efficiency of ambulation. *J Pediatr Orthop* 2007; 27: 130–6.

20 Russell D, Rosenbaum P, Avery L, Lane M. *Gross Motor Function Measure (GMFM-66 & GMFM-88) user's manual.* London: Mac Keith Press, 2002.

21 Russell DJ, Rosenbaum PL, Cadman DT *et al*. The gross motor function measure: a means to evaluate the effects of physical therapy. *Dev Med Child Neurol* 1989; 31: 341–52.

22 Schaubert KL, Bohannon RW. Reliability and validity of three strength measures obtained from community-dwelling elderly persons. *J Strength Cond Res* 2005; 19: 717–20.

23 Sherrington C, Lord SR. Reliability of simple portable tests of physical performance in older people after hip fracture. *Clin Rehabil* 2005; 19: 496–504.

24 Lord SR, Murray SM, Chapman K, Munro B, Tiedemann A. Sit-to-stand performance depends on sensation, speed, balance, and psychological status in addition to strength in older people. *J Gerontol A Biol Sci Med Sci* 2002; 57: M539–43.

25 Simonsick EM, Newman AB, Nevitt MC *et al*. Measuring higher level physical function in well-functioning older adults: expanding familiar approaches in the Health ABC study. *J Gerontol A Biol Sci Med Sci* 2001; 56: M644–9.

26 Gan SM, Liao HF. The reliability study and comparison of sit-to-stand repetitive maximum capacity in children with cerebral palsy and children without disability. *Formos J Phys Ther* 2002; 27: 292–302.

27 Hwang AW, Liao HF, Hsu AT, Gan SM, Lee CR. Reliability of Nicholas hand-held dynamometer of muscle strength measurement in children with cerebral palsy and non-disabled children. *Formos J Phys Ther* 2002; 27: 69–82.

28 Biering-Sørensen F. Physical measurements as risk indicators for low-back trouble over a one-year period. *Spine* 1984; 9: 106–19.

29 Liao HF, Jeng SF, Lai JS, Cheng CK, Hu MH. The relation between standing balance and walking function in children with spastic diplegic cerebral palsy. *Dev Med Child Neurol* 1997; 39: 106–12.

30 Portney LG, Watkins MP. *Foundations of clinical research: applications to practice*, 3rd edn. Upper Saddle River: Pearson Education Inc, 2009.

31 Mong Y, Teo TW, Ng SS. 5-repetition sit-to-stand test in subjects with chronic stroke: reliability and validity. *Arch Phys Med Rehabil* 2010; 91: 407–13.

32 McCarthy EK, Horvat MA, Holtsberg PA, Wisenbaker JM. Repeated chair stands as a measure of lower limb strength in sexagenarian women. *J Gerontol A Biol Sci Med Sci* 2004; 59: 1207–12.

33 Shum GL, Crosbie J, Lee RY. Three-dimensional kinetics of the lumbar spine and hips in low back pain patients during sit-to-stand and stand-to-sit. *Spine (Phila Pa 1976)* 2007; 32: E211–19.

34 Damiano DL, Abel MF. Functional outcomes of strength training in spastic cerebral palsy. *Arch Phys Med Rehabil* 1998; 79: 119–25.

35 Goh HT, Thompson M, Huang WB, Schafer S. Relationships among measures of knee musculoskeletal impairments, gross motor function, and walking efficiency in children with cerebral palsy. *Pediatr* 2006; 18: 253–61.

36 Kramer J, MacPhail H. Relationship among measures of walking efficiency, gross motor ability, and isokinetic strength in adolescents with cerebral palsy. *Pediatr* 1994; 6: 3–8.

37 Eek MN, Beckung E. Walking ability is related to muscle strength in children with cerebral palsy. *Gait Posture* 2008; 28: 366–71.

38 Whitney SL, Wrisley DM, Marchetti GF *et al*. Clinical measurement of sit-to-stand performance in people with balance disorders: validity of data for the Five-Times-Sit-to-Stand Test. *Phys Ther* 2005; 85: 1034–45.