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Intraobserver Reliability and Construct Validity of the Squat Test in Children With Cerebral Palsy

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Purpose: This study evaluated intraobserver reliability and construct validity of the squat test to assess lower extremity strength in children with cerebral palsy (CP) and spastic diplegia.
Methods: Children with CP performed 2 trials of the squat test and calculated the intraclass correlation coefficient to evaluate intraobserver reliability. Correlations between outcomes of hand-held dynamometry (HHD) of knee extensor strength and an 8-repetition maximum (8RM) leg press test and the squat test were calculated to evaluate construct validity.
Results: Excellent intraobserver reliability was observed for the squat test. Correlations between squat test performance and HHD knee extension and 8RM leg press test demonstrated good construct validity.
Conclusions: The squat test is a reliable and valid tool to assess lower extremity strength in children with CP and spastic diplegia. The squat test is inexpensive and less time-consuming, and therefore particularly suitable for clinicians. (Pediatr Phys Ther 2020;32:399–403)

Key words: cerebral palsy, lower extremity, muscle strength, reliability, validity

INTRODUCTION

Cerebral palsy (CP) describes a group of permanent disorders in the development of movement and posture, attributed to nonprogressive disturbances that occurred in the developing brain.[1] The motor disorders are often accompanied by secondary neuromuscular and musculoskeletal impairments, such as muscle weakness.

Muscle weakness is present among all children with CP (ie, with different types and severity levels).[2] Isometric torque levels differed among children with CP who are walking, showing higher torque levels in children with CP classified in Gross Motor Function Classification System (GMFCS) level I than GMFCS levels II to III across different lower limb muscle groups.[3] Children with CP are particularly weaker than children without CP in knee extensors, ankle dorsiflexors, and plantar flexors.[4] These reduced muscle strength levels influence measures of gross motor function, physiological function, and mobility capacity.[3-6] Muscle strength is therefore considered an important factor in attaining and maintaining mobility, self-care, and social functioning in children with CP.[7,8]

As a result, there is an increase in recognition for strength training and testing for individuals with CP. In clinical practice, the use of functional strength tests to assess muscle strength in children with CP recently increased, as opposed to static strength testing.[2] The squat test, as part of the standard physical examination for children with CP in the Netherlands, has been used in rehabilitation settings on a daily basis.[9] During the squat test, children perform 2-legged deep squat movements, resulting in the repetition maximum (RM) of squats.[9] Discriminant validity has been reported of the squat test to assess lower extremity strength in children with bilateral spastic CP.[10] However, test-retest reliability and other types of validity have not been determined.

Our goal was to evaluate intraobserver reliability and construct validity of the squat test in children with CP and spastic diplegia.

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METHODS

Study Design

This study was conducted in 2 outpatient clinic rehabilitation settings in the Netherlands, of which 1 cohort participated in the intraobserver reliability part (Amsterdam UMC, Location VUmc, Amsterdam) and 1 cohort participated in the validity part (Rehabilitation Center Heliomare, Wijk aan Zee). Prior to testing, parents/legal guardians of children with CP gave their consent to participate in the study. In addition, children of 12 years and older gave their assent. The study protocol was approved by the local medical ethical committee.

Participants

Inclusion criteria for the study were a diagnosis of spastic CP with bilateral involvement, GMFCS level I, II, or III, and between 6 and 17 years old. Participants who underwent a selective dorsal rhizotomy (SDR) or multilevel orthopedic surgery in the year prior to this study or were treated with botulinum toxin or serial casting in the 6 months prior to this study were excluded from participation.

Testing Procedure

All tests were performed on the same day, with a minimum of 10-minute rest between each test. All examiners, 2 pediatric clinical gait analysts and 1 pediatric physical therapist, had several years of experience in performing all the tests described later, and received additional training to assure guidelines were strictly followed.

Squat Test. The squat test involved the standardized execution of repetitive 2-legged deep squat movements until exhaustion, with a maximum of 20 squats.[10] The starting position was standing in an upright position followed by a deep squat movement characterized by maximal knee and hip flexion, after which the child returned to starting position. The examiner performed squats simultaneously while standing in front of the child. The child was allowed to hold hands of the examiner for balance control only. The pace was set by the examiner at approximately 1 squat (descent and ascent phase) every 2 seconds. The test was ended if (1) the child started to show compensatory strategies, such as forward or sideward trunk lean, or leaning on the examiner to stand up, (2) pace dropped to 1 squat every 5 seconds, or (3) the child could not stand up from deep squat position. The number of well-executed squat movements was taken as the outcome of the test. In order to determine intraobserver reliability, the squat test was performed twice, on the same day, with a rest of at least 10 minutes in between. If participants performed the maximum of 20 squats during both trials, they were excluded from reliability analyses.

Hand-Held Dynamometry. Maximal isometric knee extension strength was assessed by measuring peak force using a hand-held dynamometer (HHD; microFET Handheld Dynamometer, ProCare, Groningen, the Netherlands).[11] Test position of the participant was standardized as sitting in upright position on a consultation table with knees and hips flexed in 90°. The pelvis was stabilized by one of the researchers to prevent hip extension. Arms were held crossed in front of participants' chest. Participants exerted maximal effort against the HHD, which was held stationary by the examiner against the anterior side of the tibia perpendicular to the movement direction (5 cm proximal to the midline of the medial and lateral malleoli). Maximal effort was given according to the "make test," during which participants gradually build up force against the dynamometer for 5 seconds.[12] After 2 to 3 familiarization trials, 3 trials were executed with a 30-second rest between trials. The distance between the position of the HHD and the top of the fibula head was measured to obtain the lever arm.[13] For each individual trial, torque (Nm) was calculated by multiplying peak force (N) with lever arm (m). Torque was normalized to body weight (Nm/kg). No differences were observed in torque of most and least affected legs (paired-samples *t* test: $P = .215$). Hence, the average torque of both leg trials (6 trials total) was taken as total knee extension strength for analysis.[14]

Leg Press Test. Submaximal strength of the lower extremity muscles was measured with an 8-repetition maximum (8RM) test on a leg press.[15] Resistance (in kg) was applied by the leg press ergometer (EN-Dynamic Seated Leg Press, Enraf Nonius, the Netherlands), which was specifically adapted for children by means of an elevated footplate. To determine the 8RM, participants started with 3 unloaded repetitions to practice correct execution. Each repetition was completed through full (possible) range of motion of knee flexion, with adequate speed (extension: 2 seconds; flexion: 2 seconds). Two warm-up trials of 3 repetitions were completed at 50% and 70% of the predicted 8RM, respectively. The predicted 8RM was based on participants' body weight and GMFCS level.[15] The third trial was completed at 100% of predicted 8RM until muscle exhaustion, or until a maximum of 10 repetitions. When the participant executed a repetition incorrectly, it was not counted and the trial was ended. If a participant executed 10 correct repetitions, 10% to 20% load was added. After a 3-minute break, the trial was repeated until the participant was able to complete 7 to 9 repetitions, but no more. The final resistance of the 8RM test was expressed as a percentage of body weight.

Statistical Analysis

All variables, including participants' characteristics and results of the strength tests, were tested for normality using the Shapiro-Wilk test. Descriptive statistics were used to summarize these outcome variables.

Reliability. Intraobserver reliability of 2 trials of the squat test was determined by calculating the 2-way random (absolute agreement) intraclass correlation coefficient (ICC) using variance component analysis[15]:

$$\mathrm{ICC}\,(2,\mathrm{k}) = \sigma_B^2/(\sigma_B^2 + \sigma_W^2 + \sigma_{residual}^2)$$

in which σ_B^2 represents the variance between participants, σ_W^2 the variance within participants, and $\sigma_{residual}^2$ the residual variance. Excellent reliability criteria for ICC values were set at more than 0.90.[16] To assess the amount of error in units of the measurement associated with repeated measures, the standard error of the measurement ($\mathrm{SEM} = \sqrt{\sigma^2 w + \sigma_{error}^2}$) and the smallest detectable difference (SDD $= 1.96 \times \text{SEM} \times \sqrt{2}$) were calculated.[17] SEM and SDD were reported in the actual units of the measurement (ie, number of squats). For the test-retest reliability, the Bland-Altman plot was constructed to examine the systematic errors across the range of measurements.[18] In addition, potential systematic errors were tested using a paired *t* test.

Validity. To investigate construct validity of the squat test, hypotheses were formulated a priori based on correlations with other commonly used instruments in children with CP and in accordance with the COnsensus-based Standards for selection of health status Measurement INstruments (COSMIN) checklist.[19] Pearson correlation coefficients (r) were calculated between the performance on the squat test (ie, maximal number of correctly executed squats) (dependent variable), and (1) knee extension strength measured by the HHD (Nm/kg); and (2) the 8RM leg press (% of body weight) (independent variables). The effect size was calculated to define linear regression models as not related ($r < 0.2$), weak ($0.2 \leq r < 0.5$), moderate ($0.5 \leq r < 0.8$), or strong ($r \geq 0.80$).[20] The following hypotheses were tested:

1. The relationship between the repetition maximum of squats and the knee extension HHD was expected to be moderate to strong ($0.5 \leq r < 0.8$), based on the different constructs of strength (ie, dynamic vs static) and number of joints involved (ie, multijoint vs single-joint).
2. The relationship between the repetition maximum of squats and the 8RM leg press was expected to be strong ($r \geq 0.8$), based on similar constructs of strength (ie, dynamic and multijoint movement).

Analysis of the data was completed using SPSS 20.0 (SPSS, Chicago, Illinois). The level of α value was $P = .05$.

RESULTS

Participants

Intraobserver reliability was assessed in 37 children with CP, and validity was assessed in a separate group of 15 children with CP. Participants' characteristics of the groups are in the Table. The frequency distribution of squat performance of all participants is in Figure 1.

Reliability

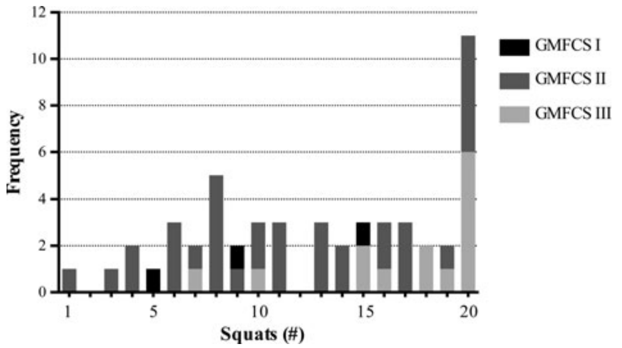

Fig. 1. Frequency distribution of the squat test performance of all participants (total n = 52; GMFCS I: n =14; GMFCS II: n = 35; GMFCS III: n = 3). GMFCS indicates Gross Motor Function Classification System.

Participants performed during both trial 1 and trial 2 on average 12 squats (SD = 6; range = 1-20). The results of the reliability analysis was an ICC(2,k) [90% confidence interval, CI] of 0.935 [0.878- 0.966], indicating excellent reliability. The SEM of the squat test was 1.6 and the SDD was 4.4. Bland-Altman (Figure 2) plots the differences in scores between 2 squat test trials plotted against the mean values of the 2 squat test trials. The limits of agreement ranged from −4.2 to 3.9. No systematic error was observed (mean difference (SD) = −0.16 (2.1)).

Six participants (16%; boys/girls: n = 5/1; GMFCS level I: n = 2, level II: n = 4; age range = 11-17 years) performed the maximum of 20 repetitions in both trials. When excluding these 6 participants, the averages during both trial 1 and trial 2 were 10 squats (SD = 5; range = 1-20). An ICC [90% CI] of 0.935 [0.890-0.962] was observed and the limits of agreement ranged from −5.6 to 4.3. No systematic error was observed either (mean difference (SD) = −0.19 (2.3)).

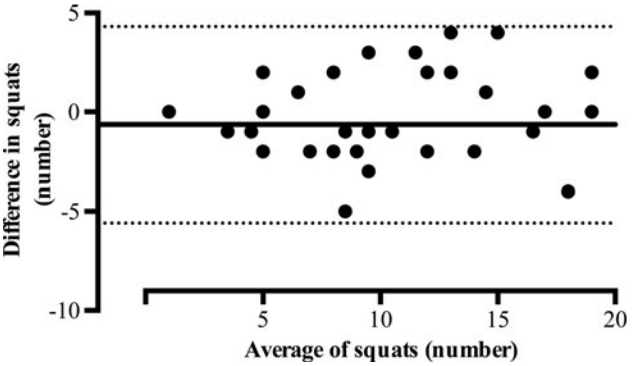

Fig. 2. Bland-Altman method plotting the difference in scores between the 2 squat trials against the mean score of the 2 squat trials. The bold line defines the mean difference and the 2 dotted lines define the limits of agreement (mean difference ± 1.96 × standard deviation).

TABLE

Participant Characteristics

Characteristics	Reliability (n = 37)	Validity (n = 15)
Gender (boys/girls)	19/18	10/5
Age, mean (SD), [range], y	11.8 (3.0), [6-17]	12.9 (2.6), [7-17]
Height, mean (SD), [range], m	1.46 (0.15), [1.15-1.85]	1.60 (0.16), [1.21-1.82]
Body mass index, mean (SD), [range], kg/m^2	18.3 (4.0), [12.9-26.4]	19.2 (3.5), [14.9-28.4]
GFMCS (I/II/III)	7/23/3	6/7/1
SDR (yes/no)	19/18	3/15

Abbreviations: GMFCS, Gross Motor Function Classification System; SDR, selective dorsal rhizotomy.

Validity

The 15 participants in the validity study performed an average of 16 squats (SD = 4; range = 8-20), a knee extension torque of 0.98 Nm/kg (SD = 0.25 Nm/kg; range = 0.39-1.46) measured using HHD, and an 8RM of 160% of body weight on the leg press test (SD = 40%; range = 88 – 217). Pearson correlation coefficient (*r*) for maximal number of squats and HHD (in Nm/kg) was r = 0.652 and for maximal number of squats and 8RM leg press (% of body weight) *r* = 0.902 (Figure 3).

DISCUSSION

Intraobserver reliability of the squat test is excellent, with an ICC of 0.93. Based on these results, we may conclude that the squat test is reliable within examiners to assess differences in lower extremity strength between individuals. The SEM and SDD, which provide information about measurement error in units of the squat test within persons, showed to be 1.6 squats for SEM (13% of mean squat performance) and 4.4 squats for SDD (37% of mean squat performance), and hence were similar to those of HHD tests in children with CP, which showed SDD values that ranged from of 23% to 34% (of mean HHD) for knee extensor and flexor muscle groups.[13] The squat test is however easier to perform in clinical practice, since no devices are necessary. The improvements in squat test performance of a minimum of 4 squats should be reached to be able to measure an actual change beyond measurement error. Sensitivity of the squat test to capture individual changes may therefore be limited. By taking the average of multiple squat trials, intraobserver reliability can improve, as previously reported by Van Vulpen et al[21] in HHD measurements for children with CP. Future research should confirm whether taking the average of multiple trials increases intraobserver reliability, as well as interobserver reliability.

Construct validity of the squat test as an outcome measure for lower extremity strength of children with CP was examined based on the framework provided by the COSMIN.[19] A priori formulated hypotheses were confirmed. This finding supports a previous study, where the squat test demonstrated discriminative validity by distinguishing lower extremity strength of children with CP from peers developing typically.[10] When no golden standard is available, the results of both types of validity suggest that the squat test can be considered a valid test for the assessment of lower extremity strength in children with bilateral spastic CP.[19] As hypothesized, a moderate correlation was observed between squat test performance and knee extensor HHD measurements, which is consistence with previous research, where other functional tests showed moderate correlations with HHD measurements.[22,23] In addition, a strong correlation was observed between squat test performance and the 8RM leg press test. The differences between these relationships can be explained by the different conditions that were taken into account (ie, the single-legged HHD measurements and the 2-legged 8RM leg press). In addition, HHD measurements in this study were limited to knee extension contractions, while squat and leg press tests involve extension of the whole lower limb, which could also explain the different relationships with the squat test.

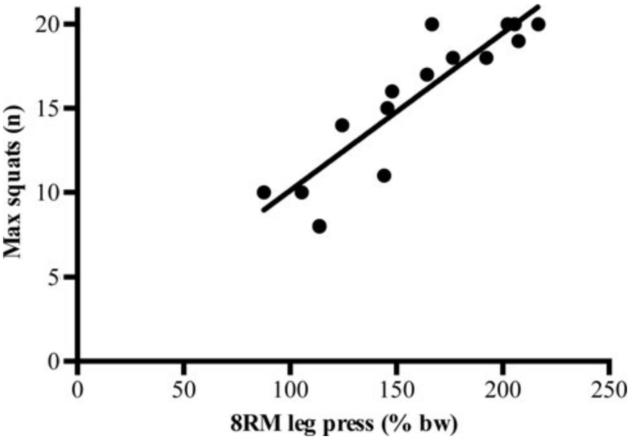

Fig. 3. Scatter plots of the (A) maximal isometric knee extension torque assessed using HDD (in Nm/kg) and (B) 8RM leg press test (in % body weight) plotted against the maximal number of squats performed. Linear regression lines are presented. bw indicates body weight; 8RM, 8-repetition maximum; HHD, hand-held dynamometry.

Although alternative strength tests are available, the squat test has some important advantages. First, squat movements include dynamic, 2-legged, and multijoint movements that are similar to movements in activities of daily life. This is particularly an advantage over HHD that assesses single-joint isometric muscle strength. In addition, the squat test is inexpensive and easier to administer compared with isokinetic testing or the leg press test. Thus, the squat test can be considered a valid and easy-to-use test to regularly test lower extremity strength to inform clinical decision-making and evaluation of strength.

Currently, the squat test, which is used as part of the standard physical examination for children with CP in the Netherlands, is terminated when children have performed 8 squats. In this case the qualification of "good strength" is given.[9,24] In this study, however, the majority of children with CP were able to perform 8 squats, but still fewer than 20 squats. By extending the range to a maximum of 20 squats, we were able to demonstrate that children with CP were limited in their lower extremity strength, and hence, it allows the squat test to also capture (changes in) strength in children with CP at GMFCS I and II.

Limitations

Trials to investigate reliability were performed on the same day and conducted by the same observer. Future research is needed to investigate interobserver reliability as well as on different days. Second, the sample was heterogeneous, with respect to age, and the sample size was relatively small. Third, since the squat test is particularly suitable for ambulant children with CP with a bilateral involvement, only children with specifically this subtype of CP were included in the study. Children with a unilateral involvement were expected to predominantly perform the squat test with their least affected leg, which provides information on the strength of the least affected leg and can lead to a ceiling effect. Hence, the results of this study may not be generalized to a cohort with a unilateral involvement. Fourth, it should be taken into account that testing construct validity is often considered to be less powerful than testing criterion validity, since in the latter situation a gold standard is available. Finally, almost half of the children with CP who participated in the reliability study underwent an SDR intervention (>12 months prior to measurements). Although this may limit generalization of the results, it is not sure what the consequences of SDR on lower extremity strength are.

WHAT THIS ADDS TO THE EVIDENCE

The squat test is reliable and valid to assess lower extremity extensor strength in children with bilateral spastic CP. Although sensitivity of the squat test may be limited, within-subject variability was similar to other strength tests that are regularly used among children with CP, and may be improved by taking the average of multiple trials. In contrast to other strength tests, however, the squat test is inexpensive and easy to administer, and therefore more suitable for clinical practice.

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