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Functional strength measurement in cerebral palsy

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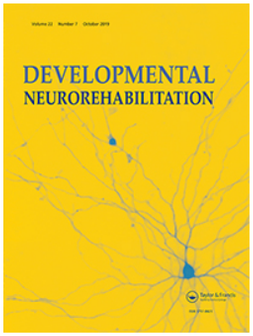

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Functional strength measurement in cerebral palsy: feasibility, test–retest reliability, and construct validity

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ABSTRACT

Purpose: No instrument exists that measures functional strength in both lower and upper extremities in children with cerebral palsy (CP). Therefore, the functional strength measurement (FSM) was tested for feasibility, test–retest reliability and validity in CP.

Methods: Thirty-seven children with CP (aged 4–10 years, Gross Motor Function Classification System I and II) participated. The most common compensations for CP were described; new item descriptions were standardized, and one item was removed. Test–retest reliability was examined. To measure convergent validity, correlations between the FSM-CP and isometric muscle strength measured with the handheld dynamometer (HHD) were determined.

Results: Test–retest reliability was considered high for all items (intra-class correlation coefficient 0.79–0.95). Significant correlations between the HHD and FSM-CP ranged from $r = 0.36$ to 0.75.

Conclusion: The FSM-CP is feasible, reliable, and valid to use in children with CP. The FSM-CP can be considered as a helpful tool in clinical practice of physical examination of children with CP.

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Cerebral palsy; children; feasibility; functional strength measurement; reliability; validity

Introduction

Cerebral palsy (CP) describes a group of permanent disorders of the development of movement and posture, and occurs from nonprogressive disturbances in the developing fetal or infant brain.[1] The prevalence of CP in Europe is estimated as 2 per 1000 births.[2] Motor impairment is the core feature in CP. Impairments in CP are multifactorial in nature and include spasticity and reduced motor selectivity, coordination, and muscle strength.[3–6] Reduced muscle strength in CP is attributed to both altered neural mechanisms, such as reduced central drive, insufficient motor recruitment, and impaired voluntary control, and muscular differences including atrophy, changes in fiber length and reduced elasticity.[7] It has been shown that muscle strength, and not spasticity, has the largest impact on motor function and daily activities in children with CP.[8]

Different methods are used to measure muscle strength in children with CP. Dekkers et al. concluded in their review that for most muscle groups the handheld dynamometer (HHD) is the preferred way to measure isometric muscle strength in children with CP.[9] However, in order to evaluate force generation, regulation and timing of force, it is essential to measure muscle strength also in a functional manner, which is more similar to activities that children with CP perform in daily activities and sports. For instance, functional strength has been shown to be an important predictor of independent walking.[10]

For children with CP functional strength, tests are available for the lower limb. Verschuren et al. developed the functional strength assessment (FSA).[11,12] The FSA focuses on dynamic functional performance of the lower extremities. It measures the number of repetitions in 30 s during three standardized functional movements (sit-to-stand, lateral step-up, and attain stand through half knee). The FSA was found to be reliable in children with CP.[11,12] However, information about its validity is lacking. In addition to anaerobic muscle endurance, muscle power is of importance in children's daily life (e.g., sprinting, jumping, throwing) and should therefore be measured. The Muscle Power Sprint test is a test measuring the power of the lower extremities and is validated for children with CP.[13] In order to determine overall functional muscle strength in children with CP, it is important to include measurements of the upper extremities. A lot of daily tasks are complex bimanual tasks and the weaker hand may determine function during these bimanual tasks.[14] The weaker hand will encounter problems in force generation (maximal voluntary contraction) and task-specific force regulation during the performance of that specific task. Hence, it is important that the therapist can reliably measure strength while executing the specific daily task of interest. Until now, an instrument that measures functional strength (both anaerobic muscle endurance and muscle power) in the lower and upper extremities is not available for the CP population.

For typically developing (TD) children (aged 4–10 years), an instrument to measure functional strength in both the lower and upper extremities does exist: the functional strength measurement (FSM).[15,16] The FSM consists of eight items matching activities of children in this age-group. Four items are related to the upper limb and four to the lower limb. Four

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items measure muscle power and four items measure the number of repetitions in 30 s. Previous research in TD children has indicated that the FSM has good internal consistency (Cronbach's alpha is 0.74) and test–retest reliability (intraclass correlation coefficient [ICC] = 0.91–0.95). To examine the convergent validity in TD, the FSM was compared with the HHD. Results showed moderate correlation (r = 0.42–0.74). The divergent validity in TD children was assessed by comparing the FSM with motor performance test (Movement-ABC-2). As expected, the correlations were low (r < 0.39) or not significant.[15,16]

It is unknown if the FSM is also suitable to measure functional strength in children with CP. Because of the physical constraints in children with CP, a study evaluating the feasibility of the FSM in children with CP is necessary. If needed, adaptations to the content and procedures of the original FSM could make the test appropriate for this target group.[17] Subsequently, it needs to be established whether the FSM is also reliable and valid in children with CP. Therefore, the first aim of this study was to investigate the feasibility of the FSM and possible item adaptation for children with CP (study Part I). Second, test–retest reliability (study Part II) and construct validity (study Part III) of the FSM in children with CP were determined. A gold standard to measure functional strength is lacking; therefore, we investigated construct validity by assessing convergent validity and known-group validity. Convergent validity was determined by comparing the FSM with HHD. Because it has been suggested that isometric and functional strength are not linearly related, moderate correlations between the FSM and HHD (0.5–0.75) were expected.[18] Furthermore, we looked at the known-group validity. Children with higher Gross Motor Function Classification System (GMFCS) level were expected to have more severe problems in generating (functional) strength in contrast to the children with lower GMFCS levels.

Method

Participants

Eligible participants were recruited from Tolbrug Rehabilitation Centre and private pediatric physical therapy practices. Inclusion criteria were spastic, dyskinetic or ataxic CP, uni- or bilateral, GMFCS I–II, MACS I–III, IQ > 70.[19,20] Participants were excluded if they had surgical procedures, e.g., single-event multilevel surgery or selective dorsal rhizotomy (in the past year, intrathecal baclofen therapy, or botulinumtoxin-A (Bont-A) injection in the past 3 months.

In total, 37 children aged 4–10 years participated (24 boys and 13 girls, median 7 years, GMFCS I n = 29, II n = 8, MACS I n = 18, II n = 17, III n = 2). The characteristics of the children with CP who participated in the three different parts of this study are presented in Table 1.

Table 1. Characteristics of the study population.

	Feasibility study (n=11)	Reliability and validity study (n=37)
	Mean (SD)	*Mean (SD)*
Age (y)	8.3 (2.1)	7.5 (1.8)
Length (cm)	133.3 (10.0)	129.8 (11.9)
Weight (kg)	29.5 (10.2)	27.3 (9.1)
	Number (n)	*Number (n)*
GMFCS I	5	29
GMFCS II	6	8
Bilateral	8	20
Unilateral left	3	12
Unilateral right	0	5
Sex		
Male	7	24
Female	4	13

BMI: Body Mass Index; cm: centimeter; GMFCS: Gross Motor Function Classification System; kg: kilogram; n: number of children; SD: standard deviation; y: years. All children who participated in the feasibility study (n = 11) also participated in the reliability validity study (n = 26).

Measures

Functional Strength Measurement

The original FSM consists of eight items measuring anaerobic muscle endurance (sit-to-stand, lateral step-up, lifting a box, and climbing stairs) and muscle power (overarm throwing, underarm throwing, chest pass, and standing long jump). In the anaerobic muscle endurance items, the number of repetitions in 30-s timeframe is administered; in the muscle power items, the distance in centimeters is measured. The eight different items are as follows: (1) overarm throwing: the child has to throw a heavy sandbag as far as possible, distance in centimeters is measured; (2) standing long jump: the child has to jump as far as possible, distance in centimeters is measured; (3) underarm throwing: the child has to throw a heavy sandbag as far as possible, distance in centimeters is measured; (4) lateral step-up: the child has to touch the floor standing with the other leg on the first step of the stairs as many time possible in 30 s, number of repetitions is counted; (5) chest pass: child sits on the floor and has to push a heavy sandbag as far as possible, distance in centimeters is measured; (6) sit-to-stand: child must stand up and sit down from a chair as many times possible in 30 s, number of repetitions is counted; (7) lifting a box: the child has to put a heavy box on top of another box as many times possible in 30 s, the number of repetitions is counted; and (8) climbing stairs: the child has to run up and down the stairs as many times possible in 30 s, the number of steps are counted (see Figure 1 for more detailed information). Participants were given the opportunity to practice every test item (with a maximum of five trials) before the test trial. Each item was examined three times and the highest score was used for the analysis. Separate item scores can be calculated and compared to a reference norm. Besides these item scores, it is also possible to calculate cluster scores for cluster muscle endurance (lateral step-up, sit-to-stand, lifting a box and stair climbing), cluster explosive power (overarm throwing, underarm throwing, standing long jump and chest pass), cluster upper extremities (overarm throwing, underarm throwing, chest pass and lifting a box), and cluster lower extremities (standing long jump, lateral step-up, sit-to-stand and stair climbing). Information about which kind of strength deficits are present (explosive power, endurance, upper extremities, or lower extremities) makes it possible to target the intervention and make the training parameters more specific. The original FSM takes 25–30 min.

Original FSM	item	FSM	FSM-CP adaptions
	Overarm throwing	Throwing a heavy bag as far as possible (centimetres).	The affected hand may be used to support the bag instead of grasping it.
	Standing long jump	Jumping forwards as far as possible (centimetres).	No adaptations.
	Underarm throwing	Throwing a heavy bag as far as possible (centimetres).	The affected hand may be used to support the bag instead of grasping it.
	Lateral step up	Touch the floor with your foot as fast as possible. Put 2 fingers against the wall for balance support (number/ 30 seconds)	More than 2 fingers may be used for support, without leaning against the wall.
	Chest pass	Pushing a heavy bag as far as possible (centimetres).	Removed.
	Sit to stand	Stand up and sit down as quickly as possible (number/ 30 seconds).	No adaptations.
	Lifting a box	Lift a plastic box filled with heavy bags onto a wooden box as quickly as possible (number/ 30 seconds).	The affected hand may be used to support the plastic box instead of grasping it. .
	Stair climbing	Climbing up and down the stairs as quickly as possible (number/ 30 seconds).	No adaptations.
Functional Strength Measurement-CP			

Figure 1. Functional strength measure (FSM) and the adaptions for FSM-CP.

Handheld Dynamometry

HHD was used to quantify isometric strength of participants. For the assessment of the HHD, the protocol of Hebert et al. was used,[21] and small adaptations were made for positions in children with CP.[22] There are two different protocols available: the "make" method and the "break" method. In the "break" method, the examiner overcomes the muscle force and stops when the limb starts to move. In the "make" method, the participant pushes maximally against the power transducer without movement. The "make" method was used, which is reported to be more reliable in children with CP.[12,21] Every movement was tested three times with 30 s rest between the trials. The best score (Newton) was used for the analysis.

Though the validity of the HHD in children with CP is unknown, it is seen as the most reliable method to measure upper extremity isometric strength in this population and has been shown to be feasible in the lower extremities.[9,23] The reliability values of the HHD in the lower extremities varied between moderate and good depending on muscle group tested, the number of trials, and the kind of method used (make or break).[12,23,24]

Procedure

This study had a cross-sectional design. Children were measured at Tolbrug Rehabilitation Centre or at the pediatric physical therapy practice where the child was being treated. Parents or legal representatives of all participants gave written informed consent prior to participation. The study was approved by the Medical Ethical Committee (ECSW2014-3107-232). Three pediatric physical therapists received a 10-h training on the assessment of the two measures: FSM and HHD. Prior to testing, the length and weight of participants were measured. During the feasibility study, the performance of the child on the FSM was filmed.

Part I: Feasibility study (T0)

First, the feasibility of the FSM for children with CP was determined. In total, 11 children with CP (7 boys and 4 girls, mean age 8.3 years, range 4–10 years, GMFCS I n = 5, II n = 6, MACS I n = 4, II n = 5, III n = 2) participated in this part of the study (Table 1). For this purpose, four criteria were formulated.

First, to confirm that the test can be used, the children with CP should be able to perform 80% of all items of the original protocol and finish at least one attempt of the muscle endurance items.

Second, in TD children, it takes about 25 min to complete the test; given that additional time was needed to explain the test procedures in this group, we considered the test time clinically feasible if it took less than 45 min.

Third, none of the children may experience pain during the test. Children were asked immediately after the test if they experienced pain during the performance of any of the items. The frequencies of "yes" and "no" were recorded. It was recommended that the children who used (walking) aids or orthotics in daily life also used these during testing.

Fourth, during the test, compensations in task performance were allowed as long as the task could be performed as the task description indicated and was in line with the functional intention of the item. For example, if the task description was based on throwing with two hands, the task item should be performed with both hands, but a different position of the hands was allowed. In this way, the individual motor strategies that are embedded in the functional approach of strength testing were respected. To determine whether the demonstrated compensations were in accordance with the functional intention of items of the FSM, an expert committee was formed who reviewed videos of all test items of the FSM. This committee consisted of three experts in functional strength testing and CP. The expert committee determined per item whether the shown performance was in line with the task description and demonstrated the use of functional strength. If the performance would differ too much from the task description or was based on constraints in mobility, muscle length, or selectivity in the children with CP, the task would be adapted or excluded in the adapted version of the FSM. After the process of reviewing the videos, the compensations which did not change the functional goal of the task were accepted by the committee. New standardized item descriptions were made based on the three criteria and was called FSM-CP. This adapted version was then used for the assessment of test–retest reliability and validity of the FSM-CP (see Figure 1).

Part II: Test–retest reliability study (T1-T2)

To examine the test–retest reliability of the FSM-CP, participants were tested twice by the same researcher within an interval of 2–3 weeks (T1-T2). All 37 children with CP participated in this part of the study (24 boys and 13 girls, mean age 7.5 years, range 4–10 years, GMFCS I n = 29, II n = 8, MACS I n = 18, II n = 17, III n = 2).

Part III: Construct validity (T1)

The same children from the reliability part of the study participated in the validity study. To assess construct validity, convergent validity was determined by comparing the scores of the FSM-CP to measures of the HHD. The following movements were measured: elbow flexion–extension, shoulder anteflexion, hip abduction–flexion–extension, and knee flexion–extension. Every movement was tested three times with 30 s rest interval. Between the FSM-CP and the HHD, there was a 15-min break.

Data Analysis

For the analysis of the test–retest reliability, ICC with absolute agreement (ICC model 2.1A) and the 95% confidence interval (CI) were determined between the two assessments of the FSM-CP. The standard error of measurement (SEM) was calculated by dividing the $SD_{difference}$ by the square root of 2 ($SD_{difference}/\sqrt{2}$).[25] The SEM gives information about the systematic measurement error. The smallest detectable change (SDC) was determined by multiplying the SD of the difference ($SD_{difference}$) with 1.96[25] The SDC is the smallest change you can measure with a measurement above this systematic error. The information about the SDC is of importance when evaluating interventions. To talk about real improvement, the pre–post difference must be larger than the SDC. Bland–Altman plots were made to visualize the measurement bias and the limits of agreement (LoA). An ICC above 0.70 was considered as good, 0.5–0.7 as moderate, and below 0.5 as low.[26]

The Shapiro–Wilk test was used to verify whether data were normally distributed. Since data of the HHD were not normally distributed, nonparametric Spearman's rho was used to determine the correlation of the mean raw scores of the HHD and FSM-CP to analyze the validity of the FSM-CP. For the Spearman's rho correlation, values <0.40 are considered low, 0.4–0.7 moderate, and >0.7 is high.

For the known-group validity, Mann–Whitney U test was performed to calculate the differences on the FSM-CP and HHD between the group of children with GMFCS I–II. GMFCS classification was used to create the two groups. Children with GMFCS classification II have more difficulties in gross motor activities (e.g., maintaining balance) and were expected to be different on the FSM-CP. We chose not to make groups based on the MACs level, because children with different MAC levels were not expected to be different on the FSM-CP. The FSM-CP does not test hand function but

functional arm use; therefore, children are allowed to use the affected hand as helping or supporting hand/arm which makes hand and finger movements of less importance.

All statistical analyses were performed with SPSS version 22. Alpha was set at 0.05.

Results

Part I: Feasibility study (T0)

Of all the items measured in the 11 children with CP, 90% were performed according to the protocol. All children with CP (100%) were able to perform the total FSM within 45 min and at least finished one attempt of the muscle endurance items (lateral step-up, sit-to-stand, lifting a box, and stair climbing). With regard to this last criterion, 8 of the 11 children were able to perform all three sets of the muscular endurance items, the other children could perform only two sets of the lateral step-up (n = 2), sit-to-stand (n = 1), and stairs climbing (n = 1) caused by fatigue. None of the children reported pain during the test.

Some compensations were seen during the test performance. The expert committee reviewed these compensations and reached consensus about what could be allowed. They reported almost all compensations as being in accordance with the functional goal of the test item, except for the item chest pass, and therefore these compensations were allowed and carefully described in the new FSM-CP protocol. The first compensation that was seen in the children with CP was that they were not able to perform the bimanual items symmetrically (overarm/underarm throwing and lifting a box) and compensated by performing these items using the affected hand for support (overarm/underarm throwing) or also using the support of the affected forearm – and not just the hand – to hold the box (lifting a box).

Second, all children with CP used more than two fingers for support during the lateral step-up. Because it was difficult for the children to make an isolated movement with two fingers, the use of five fingers for minimal touch support, without leaning, was allowed.

Many children with CP have short hamstrings and were not able to keep their back against the wall with extended legs during the chest pass. For one child, allowing more knee flexion was still not enough to perform the chest pass. Furthermore, children experienced difficulties in pronating the affected arm and in the selectivity of this movement. It is an uncommon position for these children what makes it difficult to generate muscle strength. Because of the constraints in mobility, muscle length, and selectivity in performing this item, the expert committee agreed to remove this item from the original protocol.

In conclusion, the original protocol of the FSM needed some adaptations regarding the use of the affected hand or arm and for support during lateral step-up. The item chest pass was removed from the original protocol. The instructions for these adaptations are presented in Figure 1 (FSM-CP). The FSM-CP was used in the reliability and validity study.

Part II: Test–retest reliability study (T1-T2)

Thirty-seven children with CP participated in the reliability study. For four children, it was not possible to plan the second measurement (T2) within a 2–3-week period; therefore, T2 was performed by 33 participants. Data analysis was performed with the data obtained from these 33 children and the ICC (95% CI), SEM and SDC are presented in Table 2. The ICC values are considered high for all items (ICC 0.79–0.95) (Table 2). The SEM of the explosive items ranged 6.19–21.14 cm and for the anaerobic muscle endurance items 2.14–3.46 repetitions. The SDC for the explosive items ranged between 17.17 and 57.45 cm and for the anaerobic muscle endurance items between 5.91 and 9.58 repetitions in 30 s. Bland–Altman plots showed small measurement bias. Mean difference for the explosive items ranged between 1.12 and 5.57 cm and for the anaerobic muscle endurance items between 2.06 and 3.87 repetitions in 30 s (Figures 1 and 2) and most results were within the LoA.

Part III: Construct validity study (T1)

Data from all 37 children were available for the validity study.

Convergent validity: For both the lower and upper extremities, the correlations between the scores on the FSM-CP and HHD were calculated. They are presented in Tables 3 and 4. Not all correlations were statistically significant. Those that were statistically significant showed low to high correlations between the HHD and the items of the upper extremities of the FSM-CP (r = 0.36–0.75, $p < 0.05$) and low to moderate correlations with the items of the lower extremities (r = 0.37–0.72, $p < 0.05$). For the sit-to-stand item of the FSM-CP, only one correlation was significant with HHD (hip abduction left, r = 0.43).

Known-group validity: of the total group, 29 children were classified as GMFCS I and 8 children were identified as GMFCS II. Although the children in the GMFCS II group were significantly older compared to the GMFCS I group, GMFCS I group had higher scores on seven of the eight

Table 2. Test-retest reliability of the FSM-CP.

	T1 Mean(SD)	T2 Mean(SD)	ICC (95%-CI)	SEM	SDC
Overarm throwing (cm)	156.72 (39.24)	162.96 (50.13)	0.86 (0.74 – 0.93)	21.14	46.84
Standing long jump (cm)	71.83 (28.97)	68.68 (28.68)	0.95 (0.91 – 0.98)	6.19	17.17
Underarm throwing (cm)	204.91 (63.44)	204.91 (63.50)	0.90 (0.80 – 0.95)	20.73	57.45
Lateral step up right (RM)	22.08 (8.62)	25.73 (7.91)	0.79 (0.21 – 0.92)	2.74	7.60
Lateral step up left (RM)	22.61 (8.28)	25.5 (9.16)	0.80 (0.52 – 0.91)	3.34	9.27
Sit to stand (RM)	18.86 (5.23)	20.82 (6.40)	0.82 (0.52 – 0.92)	2.14	5.91
Lifting a box (RM)	15.73 (6.48)	17.73 (7.55)	0.79 (0.54 – 0.90)	2.85	7.90
Stair climbing (RM)	42.84(16.54)	45.21(17.20)	0.95 (0.85 – 0.98)	3.46	9.58

T: time of measurement; ICC: Intraclass correlation coefficient; CI: confidence interval; RM: Repetition Maximum, cm: centimeters, SEM: standard error of measurement, SDC: smallest detectable change.

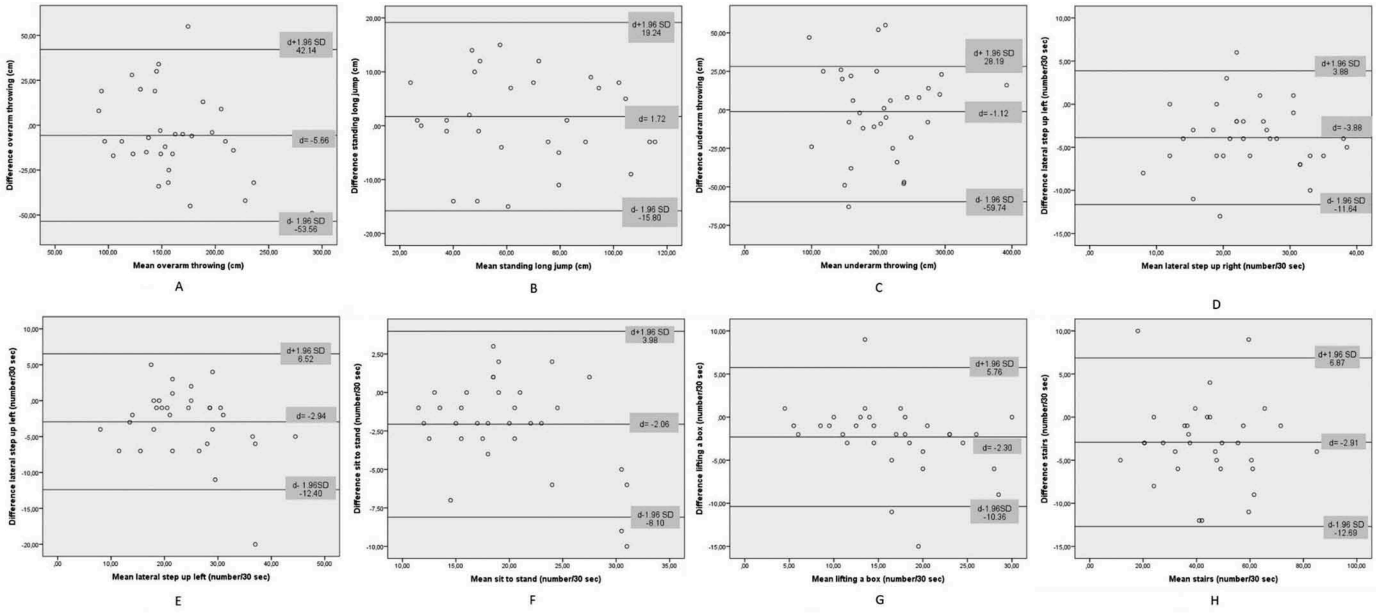

Figure 2. Bland–Altman for items of the functional strength measure (FSM-CP).

Table 3. Convergent validity of the upper extremities between the FSM-CP and HHD assessed by Spearman's rho.

	Upper extremities FSM	Overarm throwing	Underarm throwing	Lifting a box
HHD	Elbow extension R	0.55**	0.36*	0.47**
	Elbow extension L	0.41*	0.41*	0.46**
	Elbow flexion R	0.75**	0.59**	0.65**
	Elbow flexion L	0.62**	0.62**	0.57**
	Shoulder anteflexion R	0.40*	0.40*	0.69**
	Shoulder anteflexion L	0.29	0.46**	0.68**

HHD: handheld dynamometer; FSM-CP: functional strength measurement adjusted for children with cerebral palsy; R: right; L: left.
*$p < 0.05$, **$p < 0.01$.

Table 4. Convergent validity of the lower extremities between the FSM-CP and HHD assessed by Spearman's rho.

	Lower extremities FSM	Standing long jump	Lateral step-up right	Lateral step-up left	Sit-to-stand	Stair climbing
HHD	Knee extension R	0.51**	0.49**		0.24	0.47**
	Knee extension L	0.61**		0.57**	0.28	0.53**
	Knee flexion R	0.46**	0.44**		0.14	0.35*
	Knee flexion L	0.54**		0.52**	0.19	0.41*
	Hip abduction R	0.56**	0.46**		0.24	0.55**
	Hip abduction L	0.72**		0.63**	0.43*	0.60**
	Hip extension R	0.43**	0.44**		0.12	0.37*
	Hip extension L	0.47**		0.57**	0.26	0.45*
	Hip flexion R	0.30	0.40*		0.19	0.32
	Hip flexion L	0.29		0.52**	0.20	0.29

HHD: hand-held dynamometer; FSM-CP: functional strength measurement adjusted for children with cerebral palsy; R: right; L: left. *$p < 0.05$, **$p < 0.01$.

items (three were significantly higher (standing long jump, lateral step-up right and stair climbing)) than the children with GMFCS II. On the HHD, children in the younger GMFCS I group had lower scores on 12 of the 16 items (1 item was significantly lower (elbow extension right)) than the children with GMFCS II classification. The results are presented in Table 5.

Discussion

The aim of the present study was to examine the feasibility of the FSM (Part I) in children with CP and to investigate the test–retest reliability (Part II) and construct validity (Part III) of the FSM-CP in children with CP (aged 4–10 years, GMFCS I–II, MACS I–III). This information is needed before a measurement can be used in daily practice. It gives information for clinical use about the reliability of scores when examining a child and also what these scores mean for planning an intervention.

The results of the feasibility study showed that the original FSM needed some adaptations leading to a new standardized protocol (FSM-CP). One item was removed from the original protocol (chest pass). The FSM-CP was found to be reliable and seems valid to measure functional muscle strength in children with CP in clinical settings.

In the first part of this study, some compensations were seen in the children with CP when performing items of the FSM. The compensations seen were related to specific features of children with CP. Children with CP, specifically children with higher MACS levels, have problems with spatial and temporal aspects of bimanual coordination.[24]

Table 5. Difference between GMFCS1 and GMFCS 2 on FSM-CP and HHD.

		GMFCS 1 (n = 29) median (min–max)	GMFCS 2 (n = 8) median (min–max)	Mann–Whitney U p-value
	Age	7 (4–10)	9.5 (6–10)	0.02
FSM-CP	Overarm throwing (cm)	147 (92–266)	162 (103–210)	0.39
	Standing long jump (cm)	74 (33–125)	42 (27–112)	**0.05**
	Underarm throwing (cm)	210 (120–400)	146 (88–282)	0.10
	Lateral step-up R (RM)	25 (4–41)	16 (4–25)	**0.01**
	Lateral step-up L (RM)	25 (4–42)	19 (6–25)	0.10
	Sit-to-stand (RM)	20 (11–28)	13 (11–21)	**<0.01**
	Lifting box (RM)	16 (5–31)	14 (5–22)	0.43
	Stair climbing (RM)	46(20–83)	33 (9–57)	**0.03**
HHD	Elbow extension R	76.29 (44.13–142.20)	93.32 (65.70–161.81)	**0.03**
	Elbow extension L	78.45 (48.00–138.27)	100.38 (39.23–113.76)	0.40
	Elbow flexion R	71.10 (49.03–141.22)	94.05 (39.23–135.70)	0.47
	Elbow flexion L	71.67 (46.20–150.04)	79.30 (39.23–133.37)	0.72
	Shoulder anteflexion R	78.45 (56.90–156.91)	98.55 (57.86–123.56)	0.79
	Shoulder anteflexion L	90.42 (48.40–144.50)	69.63 (52.96–108.85)	0.17
	Knee extension R	159.85 (80.90–213.78)	167.69 (87.28–200.60)	0.91
	Knee extension L	144.16 (79.60–283.41)	147.59 (87.28–185.35)	0.70
	Knee flexion R	112.78 (58.20–216.73)	134.35 (84.34–181.90)	0.23
	Knee flexion L	113.21 (53.30–199.07)	127.49 (83.60–174.56)	0.56
	Hip abduction R	115.46 (53.30–261.84)	112.15 (60.80–157.89)	0.51
	Hip abduction L	111.31 (59.90–220.65)	100.25 (60.80–131.41)	0.31
	Hip extension R	152.49 (98.07–392.27)	162.79 (104.10–306.95)	0.62
	Hip extension L	156.91 (73.55–329.50)	145.63 (67.67–225.55)	0.54
	Hip flexion R	126.73 (73.80–214.00)	152.98 (85.40–226.90)	0.15
	Hip flexion L	132.88 (72.90–229.48)	153.36 (107.20–234.38)	0.10

HHD: hand-held dynamometer; FSM-CP: functional strength measurement adjusted for children with cerebral palsy; R: right; L:left, cm: centimeters; RM: Repetition Maximum.
bold: significance p≤0.05.

Likely, explanations are contractures, reduced joint mobility, decreased selectivity, and grip strength.[27–29] Therefore, the new protocol allowed that specific test items could be performed using the affected arm for support. This is a common way for children with CP to perform such daily activities; they generally make use of working and supporting hand in bimanual tasks.[29] The physical changes related to CP, such as reduced range of motion and muscle length, have contributed to the limitations in performing the chest pass.[6,30,31] Therefore, this item was removed from the protocol. During the lateral step-up (FSM-CP), children were allowed to use more fingers for support, instead of the two-finger support in the original FSM protocol, because children with CP had problems in dissociated movements of the fingers. All admissible compensations were standardized and described in detail in the FSM-CP protocol. There is a large variability in the clinical symptomatology of children with CP. This makes developing norms not realistic. However, the FSM-CP can be used as an evaluative instrument pre–post intervention by looking at pre–post differences per item. Evaluating interventions is important as it may help to determine if the training stimulus used in the intervention was adequate.

In the second part of the study, we examined the test–retest reliability. Comparable to the study in TD children, the test–retest reliability of the FSM-CP has shown to be high.[15] The SDC for the explosive items ranged between 17.17 and 57.45 cm and for the anaerobic muscle endurance items between 5.91 and 9.58 repetitions in 30 s. If a child, for instance, has problems with the explosive strength in jumping and one reexamines this child after a period of intervention, it has to improve the score on the item standing long jump for more than 17.17 cm (SDC long jump is 17.17) to be able to say that the child improved.

The third research question concerned the convergent and known-group validity of the FSM-CP. As expected, the comparison of the scores on the FSM-CP with the HHD showed mostly moderate correlations. The HHD measures isometric muscle force for a one-directional single joint movement, whereas the items for functional strength use dynamic movements in specific tasks as grasping a box, lift it and putting it down. These moderate correlations are comparable with those from our previous study (r = 0.42–0.74) in which the correlation between the FSM and HHD was investigated in TD children.[15] In studies examining other instruments, also moderate correlations between functional strength and isometric strength were found in healthy adults and TD children and in children with CP.[32–34]

Unlike the study in TD children, there were no significant correlations (except for hip abduction left) between the HHD and the item sit-to-stand of FSM-CP.[15] These results in the sit-to-stand task corroborated with the results among other studies in children with CP which also found differences in sit-to-stand performance in children with CP compared to TD peers.[35,36] Sit-to-stand is a biomechanical demanding task which requires not only muscle strength but also high levels of neuromuscular coordination and postural control, which are known to be impaired in children with CP.[10,30,31,37–39] Kumban et al. reported moderate correlations between five-times-sit-to-stand test and the timed up and go test (TUG) and the Berg Balance Scale (BBS).[40] The TUG and BBS are measures used in previous research for balance and postural control in children with CP.[41] This indicates that these factors are of importance in children with CP when performing the sit-to-stand movement.

The known-group validity analysis showed lower scores on the FSM-CP in the children with GMFCS II compared to children with GMFCS I, despite the fact that the children with GMFCS I were significantly younger. This confirmed our hypothesis. Wang et al. also found that children with lower GMFCS I classification have lower levels of functional strength measured with the five-times sit-to-stand test.[34] Comparable results were found for scores on the lateral step-up, which were lower in children with GMFCS I in comparison with children with GMFCS II.[42] We found significant differences in the lower extremity items but not in the upper extremity items. This was not expected. It could be explained by the fact that seven of the eight children with GMFCS II were bilaterally affected, having higher lower limb spasticity compared to upper limb.[43]

Looking at the values of the HHD and the FSM-CP, we see a reversed pattern. Here, we see higher scores on isometric strength items (only one was significant) in the GMFCS II group consisting of the older children. This emphasizes that functional strength and isometric strength are different constructs, which may have different developmental trajectories. In functional strength measures, force generation, regulation and timing of force are of importance. Furthermore, in the repetitive items (lateral step-up, sit-to-stand, lifting a box, stair climbing), inter- and intramuscular coordination is required when switching between agonist and antagonist contractions.[12] Also, dynamic postural control was found to be related to activities where functional strength is needed.[10]

This study has some limitations. The sample size was rather small and there was variation regarding the level of CP (level of GMFCS and MACS, and unilateral/bilateral affected). However, children with CP form a heterogenic group of children; therefore, this variability can also be seen as positive point regarding the external validity of our study. Larger studies are necessary to investigate the responsiveness of the FSM-CP and to compare scores of children with different GMFCS levels. In this study, the HHD was used to determine the construct validity of the FSM-CP, because there is no gold standard to measure isometric strength. It is important to determine other forms of validity by hypothesis testing in future studies. We suggest to validate the FSM-CP by comparing the scores with sprint tests and biodex for convergent validity and with gross motor fine motor and goal attainment scaling for discriminant validity.

Conclusions

The current study shows that the FSM is feasible in children with CP, aged 4–10 years, GMFCS I–II, MACS I–III with the new protocol with adapted item descriptions. Furthermore, the items of the FSM-CP showed to be reliable and seemed valid to measure functional strength in this target group. Measuring functional strength is important in children with CP, because it is more related to activities in daily life, such as walking. In clinical practice, both isometric and functional strength should be tested because they provide relevant and different information.

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Declaration of interest

The authors report no conflicts of interest. The authors alone are responsible for the content and writing of the paper.

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