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Original Research

Test–Retest Reliability of a Static and Dynamic Motor Fatigability Protocol Using Grip and Pinch Strength in Children With Cerebral Palsy

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Abstract

Objective. The purpose of this study was to investigate the test–retest reliability, measurement error, and interpretability of new motor fatigability outcomes of grip and pinch strength for children with unilateral cerebral palsy (UCP).

Methods. Motor fatigability during grip and pinch strength was measured twice (within 48 hours) in both hands of 50 children (mean age = 11 years 2 months; 14, 31, and 5 children with Manual Ability Classification System levels I, II, and III, respectively) using a 30-second static and dynamic maximum exertion protocol. For static motor fatigability, the Static Fatigue Index (SFI) and mean force (F_{mean}) in the first (F_{mean1}) and last (F_{mean3}) 10 seconds were calculated. For dynamic motor fatigability, F_{mean1}, F_{mean3}, and the number of peaks in the first and last 10 seconds were calculated.

Results. For static motor fatigability, the intraclass correlation coefficients (ICCs) were moderate to high for F_{mean1} and F_{mean3} (0.56–0.88), and the SFI showed low to moderate reliability (ICC = 0.32–0.72). For dynamic motor fatigability, the ICCs were moderate to high for all outcomes (0.54–0.91). The standard error of measurement agreement and the smallest detectable difference agreement were large in all outcomes, except for the SFI in static motor fatigability. Details per age group are provided. In general, younger children (6–11 years old) showed lower reliability than older children (12–18 years old).

Conclusion. Most outcome measures for static and dynamic motor fatigability of grip and pinch strength show moderate to high reliability in children with UCP, indicating that these tests can be used reliably to investigate the presence of motor fatigability in UCP, especially in older children. Standard error of measurement agreement and smallest detectable difference agreement indicated that these outcome measures should be interpreted with caution when evaluating change.

Impact. Most of the proposed outcome measures for static and dynamic motor fatigability of grip and pinch are reliable in children with UCP and can be used for discriminative purposes.

Keywords: Anatomy, Cerebral Palsy, Fatigue, Hand, Hand Strength, Neurology

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Introduction

Cerebral palsy (CP) is the most common cause of motor disability in children, with a prevalence of approximately 1.5 to 3/1000 children.[1] Unilateral spastic CP (UCP), where 1 side of the body is more involved, is present in 20% to 30% of children with CP.[2–4] Children with UCP often experience several motor impairments in the upper limb of the affected side, such as increased muscle tone, muscle weakness, or reduced selectivity.[2–4] These problems are among several caused by upper motor neuron syndrome, which impairs motor control and causes muscle weakness.[5] A secondary cause of impaired muscle strength production is an altered fiber type distribution, that is, a predominance of type I fibers in children with UCP compared with children with typical development.[6] The reduced ability to produce and sustain strength, known as motor fatigability, is one of the impairments that affect activities of daily living, such as carrying objects or holding on to a climbing frame in a jungle gym.[4,7] This in turn hampers independence and quality of life. In the current study, motor fatigability is defined as "the magnitude or rate of change of motor performance on an objectively measured reference criterion after any type of voluntary activity or exercise."[7,8] Motor fatigability is further divided into static and dynamic motor fatigability, depending on the type of motor task.[7–9]

Currently, only a limited number of studies have investigated static or dynamic motor fatigability in CP using multiple protocols and outcome measures.[9] Most studies used isometric protocols of sustained grip strength and elbow flexion strength.[10–15] Two of these used a 30-second maximum grip-strength task and calculated the Static Fatigue Index (SFI) on the basis of the area under the force-time curve.[10,11] Other methods for calculating motor fatigability included the use of various electromyography-related outcome measures.[13,16] Importantly, none of these outcome measures has yet been tested on clinimetric properties. However, without knowledge of reliability (intraclass correlation coefficients [ICC] or measurement error), it is impossible to determine whether differences between 2 measurements are due to measurement error or a real difference between the measurements. Therefore, reliability, measurement error, and interpretability of the protocols need to be determined prior to application for both discriminative and evaluative purposes in research and clinical practice.[10,11,14] These properties ideally should be investigated according to the Consensus-Based Standards for the Selection of Health Measurement Instruments (COSMIN) criteria.[17,18]

In the present study, we investigated test–retest reliability, measurement error, and interpretability of outcome data for static and dynamic motor fatigability in children with UCP.[18,19] Static and dynamic motor fatigability were calculated on the basis of a 30-second maximal grip and pinch strength task using sustained and repetitive contractions, respectively. These protocols have been proven to be reliable in other neurological patient populations as well as in children with typical development.[19–21] Furthermore, the tasks performed with these tests have shown to be important in daily life of children with UCP.[4,22] The results of the current study will lead to insights into the test–retest reliability of the new motor fatigability protocols.

Methods

Participants

Fifty children with UCP were recruited from rehabilitation centers, hospitals, and schools for special education in Belgium, the Netherlands, and the United States between July 2018 and July 2020, the number chosen being based on COSMIN criteria indicating that a total of 50 children would result in adequate methodological quality and the sample size being feasible.[18] Children were included if they were diagnosed with spastic UCP; between 6 and 18 years old; capable of understanding the instructions; and Dutch, Flemish, or English speaking. Children were excluded if they had participated in vigorous strength training of the upper limb in the past 6 months; had undergone surgery or botulinum toxin injections in the upper limb in the past 6 months; and had contractures in the upper limb that impaired performance of the tasks. Children and/or parents gave written informed consent prior to the measurements. This research was approved by the Medical Ethical Committee of Hasselt University (CME2018/069), Maastricht University (2019–1168), and Teachers College, Columbia University (New York, NY, USA) (IRB 13–220). The funders played no role in the design, conduct, or reporting of this study.

Descriptive variables were collected, including age, sex, affected hand, and Manual Ability Classification System level.[23] The children were asked not to participate in intensive fatigable exercises of either upper limb on the day before and on the day of testing.

Procedures

Each child was measured twice by the same tester within 48 hours with a Biometrics E-LINK H-500 Hand Kit (Biometrics Ltd, Newport, UK). Children sat in an adjustable chair with their back against the backrest, feet flat on the floor, arms leaning on armrests, elbows bent at 90 degrees, and with a neutral wrist position.[10] There was no support of the shoulder. Static motor fatigability was measured first, starting with the grip fatigability followed by pinch fatigability measurement. First, the less affected hand was tested, followed by the more affected hand. Subsequently, dynamic motor fatigability was measured using the same procedure.

The grip and pinch dynamometers were not supported by the tester. Two testers, with 3 and 40 years of experience in the clinical evaluation of children with UCP, were extensively trained to perform the tests. First, a written protocol was developed by both testers. Then, testers performed pilot testing together in 10 children with UCP to further standardize the protocol. Furthermore, a detailed log was written after testing each child, noting any irregularities during measurements. Forces are given in kilograms. The handle position of the Hand Kit can be adjusted to the size of the hand. There are 3 different positions, the correct one being that at which the end of the handlebar approximately lined up with the distal end of the metacarpal.

Measurements

Static motor fatigability was measured first during a 30-second sustained maximal contraction using the grip and pinch dynamometer. First, the less affected hand was tested. The child was asked to squeeze as hard as possible for 30 seconds. Instructions were standardized across testers. Visual

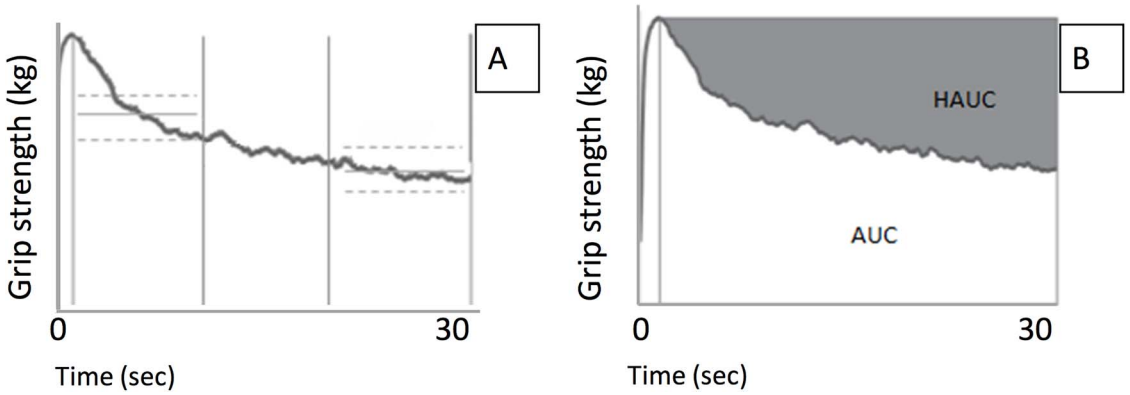

Figure 1. (A) Calculation of mean force (F_{mean}) within 3 time slots of the static motor fatigability task. Continuous horizontal line = F_{mean}; dashed lines = SD of force. (B) Schematic representation of the areas used to calculate the Static Fatigue Index. AUC = area under the force-time curve; HAUC = hypothetical area under the force-time curve.

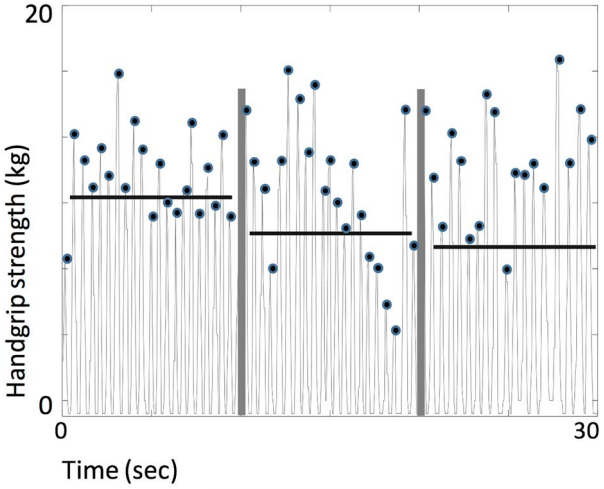

Figure 2. Schematic representation of outcome measures for dynamic motor fatigability. Bullets = peaks; horizontal lines = mean force (F_{mean}).

feedback of the residual time was provided to the child while performing the task. A measurement was successful if the child reached the peak force within the first 10 seconds of the measurement. An example of a force-time curve of this 30-second maximum exertion protocol is shown in Figure 1.

Dynamic motor fatigability was subsequently measured where the child had to squeeze repeatedly as hard and fast as possible during a 30-second period. Again, instructions were standardized across testers. The measurement was successful if the child repeatedly squeezed over the entire 30 seconds regardless of the frequency. An example of the force-time curve of this dynamic protocol is shown in Figure 2.

Outcome Measures: Fatigability Parameters

Static motor fatigability was quantified with 2 outcome measures: mean force (F_{mean}) and the SFI.[12] First, the peak force within the first 10 seconds was identified, and only the curve after this peak was used in the calculations (Fig. 1). For F_{mean}, the remaining time was divided into 3 equal parts, and F_{mean} was calculated for the first and last parts of the curve (ie, mean force in the first [F_{mean1}] and last [F_{mean3}] 10 seconds) (Fig. 1A). Test–retest reliability was calculated for F_{mean} in the first and third parts of the force-time curve separately.

For the SFI, the part of the curve before the peak force was excluded from the calculation. Within the remaining curve, the area under the force-time curve and a hypothetical area under the force-time curve were calculated. The hypothetical area under the force-time curve mimics a situation in which strength would have been sustained at the maximum level during the trial and no fatigability would have been present. The SFI was calculated with the following equation: SFI = [1 (area under the force-time curve/hypothetical area under the force-time curve)] × 100 (Fig. 1B).[19,20] A higher SFI represents more fatigability. The SFI has been proven to be reliable in people with multiple sclerosis (MS) (ICC = 0.46–0.96).[19,20]

Dynamic motor fatigability was quantified by F_{mean} and the number of peaks (N_{peaks}). The 30-second force-time curve was divided into 3 equal parts (10 seconds each), and F_{mean} and N_{peaks} were calculated for the first and third parts (Fig. 2). A decrease in F_{mean} and/or a decrease in N_{peaks} between the first and third parts indicated higher motor fatigability. Test–retest reliability of dynamic motor fatigability was calculated for F_{mean} and N_{peaks} in the first and last parts of the force-time curve separately.

Data Analysis

For descriptive statistics, the mean and SD or the median and interquartile range were reported, as appropriate, for participants' ages and for the distribution for sex, affected hand, and Manual Ability Classification System level.

Prior to data analysis, curves were visually verified for accurate performance of the tests. For static motor fatigability, this included checking for peak force within the first 10 seconds of the curve. For dynamic motor fatigability, it included determining whether the child squeezed repeatedly at any pace. A peak was defined as a decrease in force of at least 50% of the preceding peak.

Reliability

To investigate test–retest reliability, 3 analyses were used. These analyses were performed for the entire group as well as separately for children between 6 and 11 years old and children between 12 and 18 years old.

First, Bland–Altman plots were performed with limits of agreement to investigate absolute agreement between the 2 measurements.[24,25] The limits of agreement were established

Table 1. Participant Characteristics[a]

Characteristic	Value
Age, mean (SD)	11 y 2 mo (3 y 7 mo)
Age, median (IQR)	11 y (6 y)
Age range	6–18 y
Sex, boys/girls	31/19
Affected hand, right/left	31/19
MACS level: I/II/III	14/31/5
Recruitment site: USA/NL/BE	22/16/12

[a]BE = Belgium; IQR = interquartile range; MACS = Manual Ability Classification System; NL = the Netherlands; USA = United States.

as the mean ± (1.96 × SD) of the difference between the 2 test measurements.

Second, Bland–Altman plots were visually checked for heteroscedasticity. To confirm or reject heteroscedasticity, the Kendall tau was used to indicate the correlation between the absolute difference and the corresponding means. If tau was >0.1, then the data were considered heteroscedastic and transformed using logarithms (base 10), after which tau was recalculated.[24,25]

Third, the ICC agreement and 95% CIs with a 2-way random model with absolute agreement were calculated for relative agreement.[25–27] The ICCs were interpreted as follows: <0.40 indicated low agreement, 0.40 to 0.79 indicated moderate agreement, and 0.80 to 1.00 indicated high agreement.[27]

Measurement Error and Interpretability

To investigate measurement error, the standard error of measurement (SEM) agreement was calculated as follows: $SEM_{agreement} = \sqrt{(\sigma_o{}^2 + \sigma_{residual}{}^2)}$, where $\sigma_o{}^2$ is defined as observer variance and $\sigma_{residual}{}^2$ is defined as residual variance. The SEM is an estimate of how repeated measures of a person using the same instrument tend to be distributed around the "true" score and is reported as an absolute value.[25,26]

The interpretability of the measurements was assessed using the smallest detectable difference (SDD) and was calculated as follows: $SDD = SEM_{agreement} \times 1.96 \times \sqrt{2}$. The SDD is the smallest statistically significant change in measurement results and is also reported as an absolute value.[25,26]

Statistical analyses were performed using SPSS Statistics 25 (IBM SPSS, Armonk, NY, USA).

Results

Participants

A total of 50 children (6–17 years old) were eligible for the study. Participant characteristics are shown in Table 1.

For static and dynamic motor fatigability, 6 and 8 children, respectively, were unable to perform all of the tests because of weakness or coordination issues. More were able to perform the test using the grip meter (42–44 children) than with the pinch meter (37–39). Also, more children were able to perform the task with their less affected hand (39–44) than with their more affected hand (42–37).

Relative reliability, SEM, and SDD results are shown in Table 2 for the entire group. Details on ICC, SEM, and SDD values in 6- to 11-year-old children and 12- to 18-year-old children are shown in Supplementary Tables 2 and 3, respectively. Additionally, means and SDs of all outcome measures at test sessions 1 and 2 are shown in Supplementary Table 1.

Bland–Altman Plots

An example of a Bland–Altman plot is shown in Figure 3, illustrating the F_{mean1} of the static handgrip in the more affected hand. Plots of all other outcome measures, including by age group, are provided in Supplementary Figures 1–7. In Figure 3, the mean systematic error is close to 0, indicating small systematic error.[24] The upper and lower dashed lines show the random error, indicating a relatively large spread of data. Also, the Bland–Altman plot shows that the variability in the difference between the 2 test sessions (test sessions 1 and 2) was similar across the range of means between test session 1 and test session 2, indicating homoscedasticity as confirmed by a tau of 0.06. Homoscedasticity was confirmed by tau calculations in all but 2 outcome measures. Log transformation of these 2 outcome measures resulted in a homoscedastic distribution of the data ($\tau = -0.81$ and -0.52 for both outcome measures). For the Bland–Altman plots and the calculation of ICC agreement, these log-transformed data were used. SEM agreement and SDD agreement calculations were performed on the original data.

Test–Retest Reliability in Static Motor Fatigability

All results regarding the reliability analyses (ICC and 95% CI) are shown in Table 2. The ICCs of F_{mean1} and F_{mean3} for grip strength ranged from 0.56 to 0.88 in both hands. For pinch strength, $ICC_{agreement}$ values ranged from 0.69 to 0.92 for F_{mean1} and F_{mean3}. $ICC_{agreement}$ values for the SFI were low to moderate, ranging from 0.32 to 0.72. In general, the ICCs were higher in the older children ($ICC_{agreement}$ for F_{mean} = 0.53–0.91; $ICC_{agreement}$ for SFI = 0.16–0.77) than in the younger children ($ICC_{agreement}$ for F_{mean} = 0.46–0.58; $ICC_{agreement}$ for SFI = 0.30–0.69).

Measurement Error and Interpretability in Static Motor Fatigability

The results for measurement error and interpretability are reported in Table 2.

For grip strength, the SEMs of F_{mean1} and F_{mean3} ranged from 1.03 to 2.13 kg in both hands. For pinch strength, the SEMs ranged from 0.23 to 0.57 kg for F_{mean1} and F_{mean3}. The SEMs for the SFI ranged from 7.89% to 13.90%.

For F_{mean1} and F_{mean3}, the SDDs ranged from 2.86 to 5.90 kg for grip strength and from 0.65 to 1.58 kg for pinch strength in both hands. The SDDs for the SFI ranged from 21.87% to 38.53%.

The SEM and SDD values were higher in the younger children (SEM for F_{mean} = 0.24–1.50 kg; SEM for SFI = 8.68%–14.34%; SDD for F_{mean} = 0.67–4.17 kg; SDD for SFI = 24.07%–39.75%) than in the older children (SEM for F_{mean} = 0.23–2.13 kg; SEM for SFI = 7.89%–13.90%; SDD for F_{mean} = 1.14–6.15 kg; SDD for SFI = 21.87%–56.49%).

Test–Retest Reliability in Dynamic Motor Fatigability

For grip strength, the ICCs showed moderate to high relative reliability (ICC = 0.79 + 0.91) for F_{mean1} and F_{mean3}. The ICCs for the number of peaks in the first (N_{peaks1}) and last (N_{peaks3}) 10 seconds showed moderate reliability (ICC = 0.58–0.81) for grip strength. For pinch strength, the ICCs ranged from 0.68 to 0.91 for F_{mean1} and F_{mean3} and

Table 2. Results of Reliability Analyses, Standard Error, and Interpretability for Static and Dynamic Motor Fatigability[a]

Hand	No. of Participants	ICC	95% CI	Mean (SD)	SEM	SDD
Static motor fatigability						
Handgrip						
More affected						
F_{mean1}, kg	42	0.73	0.503–0.858	3.30 (2.78)	1.10	3.04
F_{mean3}, kg	42	0.56	0.250–0.759	2.00 (1.47)	1.03	2.86
SFI, %	42	0.32	0.014–0.566	56.52 (13.68)	13.90	38.53
Less affected						
F_{mean1}, kg	44	0.88	0.770–0.941	10.38 (6.01)	2.13	5.90
F_{mean3}, kg	44	0.87	0.737–0.931	7.20 (4.65)	1.79	4.97
SFI, %	44	0.58	0.343–0.750	47.99 (12.14)	8.90	24.67
Pinch grip						
More affected						
F_{mean1}, kg	37	0.70	0.437–0.851	0.96 (0.91)	0.31	0.85
F_{mean3}, kg	37	0.69	0.416–0.845	0.62 (0.70)	0.23	0.65
SFI, %	37	0.56	0.309–0.735	61.19 (14.45)	10.68	29.62
Less affected						
F_{mean1}, kg	39	0.92	0.841–0.962	0.70 (0.87)[b]	0.57	1.58
F_{mean3}, kg	39	0.83	0.656–0.911	1.74 (1.07)	0.49	1.35
SFI, %	39	0.72	0.532–0.837	49.79 (13.74)	7.89	21.87
Dynamic motor fatigability						
Handgrip						
More affected						
F_{mean1}, kg	42	0.84	0.705–0.918	4.12 (3.01)	0.94	2.62
F_{mean3}, kg	42	0.79	0.619–0.892	3.00 (2.00)	0.81	2.25
N_{peaks1}, n	42	0.81	0.653–0.899	12.60 (5.64)	2.59	7.19
N_{peaks3}, n	42	0.71	0.515–0.838	11.50 (4.97)	2.92	8.10
Less affected						
F_{mean1}, kg	44	0.91	0.825–0.954	11.89 (7.18)	2.22	6.15
F_{mean3}, kg	44	0.89	0.793–0.945	8.41 (5.71)	1.93	5.35
N_{peaks1}, n	44	0.58	0.320–0.755	18.50 (7.05)	5.27	14.61
N_{peaks3}, n	44	0.63	0.392–0.783	17.44 (5.73)	3.96	10.97
Pinch grip						
More affected						
F_{mean1}, kg	38	0.68	0.451–0.828	2.23 (2.14)[b]	0.47	1.30
F_{mean3}, kg	38	0.80	0.638–0.895	0.95 (0.57)	0.41	1.14
N_{peaks1}, n	38	0.67	0.432–0.821	12.27 (5.56)	3.50	9.71
N_{peaks3}, n	38	0.69	0.468–0.832	10.79 (5.24)	3.13	8.68
Less affected						
F_{mean1}, kg	40	0.91	0.826–0.953	2.66 (1.58)	0.49	1.37
F_{mean3}, kg	40	0.79	0.612–0.891	2.13 (1.26)	0.61	1.68
N_{peaks1}, n	40	0.85	0.720–0.917	20.02 (9.29)	3.83	10.62
N_{peaks3}, n	40	0.74	0.533–0.858	17.76 (7.24)	4.01	11.13

[a]F_{mean1} = mean force in first 10 seconds; F_{mean3} = mean force in last 10 seconds; n = number of peaks; ICC = intraclass correlation coefficient; N_{peaks1} = number of peaks in first 10 seconds; N_{peaks3} = number of peaks in last 10 seconds; SDD = smallest detectable difference (%); SEM = standard error of measurement (%); SFI = Static Fatigue Index. [b]Medians and interquartile ranges for both log-transformed outcomes.

from 0.67 to 0.85 for N_{peaks1} and N_{peaks3}. For dynamic motor fatigability, the ICCs were similar across groups. In the older children, the ICCs ranged from 0.51 to 0.91 for F_{mean} in both groups, and in the younger children, the range was 0.51 to 0.91. For N_{peaks}, the ICCs ranged from 0.49 to 0.92 in the older children and from 0.61 to 0.96 in the younger children.

Measurement Error in Dynamic Motor Fatigability

For dynamic motor fatigability, the SEMs for grip strength ranged from 0.81 to 2.22 kg for F_{mean1} and F_{mean3} and from 2.59 to 5.27 kg for N_{peaks1} and N_{peaks3}. For pinch strength, the SEMs for F_{mean1} and F_{mean3} ranged from 0.41 to 0.61 kg. For N_{peaks1} and N_{peaks3}, the SEMs ranged from 3.13 to 4.01 kg. The SEMs were similar across groups (SEM for F_{mean} in older children = 0.41–2.22 kg; SEM for F_{mean} in younger children = 0.50–1.71 kg; SEM for N_{peaks} in older children = 2.54–4.02; SEM for N_{peaks} in younger children = 1.78–3.99).

Interpretability in Dynamic Motor Fatigability

For grip strength, the SDDs ranged from 2.25 to 6.15 kg for F_{mean1} and F_{mean3} and from 7.19 to 14.61 kg for N_{peaks1} and N_{peaks3}. For pinch strength, the SDDs for F_{mean1} and F_{mean3} ranged from 1.14 to 1.68 kg; for N_{peaks1} and N_{peaks3}, the SDDs ranged from 8.68 to 11.13 kg. The SDDs were lower in the younger children than in the older children (SDD for F_{mean} in older children = 1.14–6.15 kg; SDD for F_{mean} in younger children = 0.62–4.75 kg; SDD for N_{peaks} in older children = 7.51–12.91; SEM for N_{peaks} in younger children = 4.93–11.06).

Discussion

This study, using a rigorous study design, investigated the test–retest reliability, measurement error, and interpretability of 2 new protocols to measure static and dynamic motor fatigability for grip and pinch strength in children with UCP.[18]

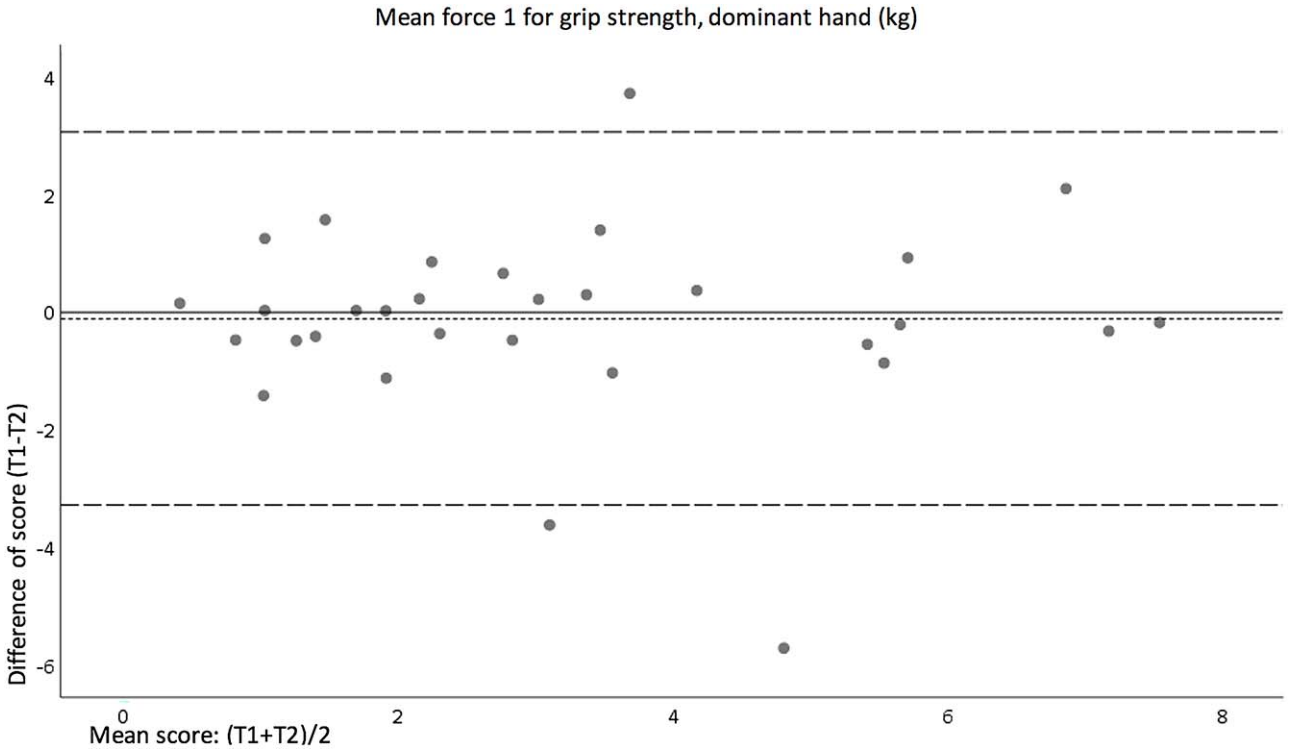

Figure 3. Bland–Altman plot of test session 1 (T1) and test session 2 (T2) of the mean force (F_{mean}) in the first 10 seconds (F_{mean1}) of the handgrip task for the dominant hand. The middle line shows the mean difference between the 2 measurements (smaller dash) and 0 (solid line), and the upper and lower dashed lines show the limits of agreement. The x-axis shows the mean of both measures, and the y-axis shows the difference between the measurements.

Children performed a 30-second maximum exertion trial of sustained and repeated dynamic contractions of grip and pinch strength. For static and dynamic motor fatigability, overall moderate to high test–retest reliability was found on the basis of the $ICC_{agreement}$, indicating that the protocols are useful for comparing the presence and severity of motor fatigability in children with UCP and children with typical development. However, measurement error and interpretability of the outcome measures on static and dynamic motor fatigability do not present favorable outcomes, and we need to be cautious when using these measures in clinical practice for evaluating changes over time.

Static Motor Fatigability

F_{mean} of static motor fatigability showed moderate to high reliability in both grip and pinch strength. $ICC_{agreement}$ in the more affected hand was lower than in the less affected one. This may have been due to poorer functioning of the more affected hand, hindering consistent performance across test periods and increasing within participant variability.[28] However, it is difficult to make direct comparisons with previous research because studies investigating reliability of the same construct are lacking for children with CP. Several studies in which the test–retest reliability was investigated in 6- to 18-year-old children with UCP using a short (3- to 4-second) maximum grip-strength measurement with the Biometrics E-LINK H-500 Hand Kit showed high reliability ($ICC_{agreement} = 0.94–0.95$).[17,22,29] This result indicates that shorter maximum grip and pinch strength protocols provide more reliable outcome measures than do sustained strength ones. These differences may be due to several factors. First, children with CP have impairments in central motor control, which hamper correct coordination between agonist and antagonist muscles and increase the variability of force for 1 child across different days (increasing the within-participant variability).[30] Second, there may have been a lack of motivation, concentration, or understanding of the length of the task in sustained strength protocols, leading to inconsistent performance. However, our sustained strength protocol does show sufficient reliability in children with UCP and provides information on the ability to sustain muscle strength over an extended period of time. These results indicate that protocols for measuring strength using a 3- to 4-second maximum grip-strength protocol and static motor fatigability using a 30-second sustained maximum grip-strength protocol are reliable in children with UCP in a cross-sectional design.

In our study, the reliability of the SFI was low to moderate (not previously investigated in children with UCP). The lowest $ICC_{agreement}$ was found for handgrip in the more affected hand, and the highest was found for pinch grip in the less affected hand. This agrees with the results of the studies of Dekkers et al and Geijen et al showing that the less affected hand showed higher reliability than the more affected one.[22,29] In adults with MS, the reliability of the SFI for grip strength was investigated by Schwid et al, although only in the dominant hand, and showed a high ICC (0.96).[19] The differences in ICCs between this study of Schwid et al and our study may have been caused by differences in population tested, protocols used, and measurement environments.[19] Possibly, in children with UCP, issues regarding cognitive or behavioral abilities such as concentration and motivation may have caused more variation between measurement sessions. Furthermore, central motor control is more affected

in children with UCP than in people with MS, resulting in more difficulties with selective motor control. Consequently, in people with MS, muscle weakness is more of an issue than coordination of muscle strength. However, in children with UCP, a combination of weakness and central mechanisms, such as selective motor control and coordination, may play a role in sustaining strength, in turn causing more variable performance between test sessions and decreasing ICC values in UCP compared with MS.

Dynamic Motor Fatigability

The ICCs of F_{mean1} and F_{mean3} in dynamic motor fatigability indicated moderate to high reliability. Here, the grip and the pinch meter showed similar $ICC_{agreement}$ values for both hands. Previous research on dynamic motor fatigability in children with UCP is lacking. In dynamic motor fatigability, $ICC_{agreement}$ values for N_{peaks1} and N_{peaks3} also showed moderate to high reliability, indicating good usability for discriminative purposes in children with UCP. Research investigating the reliability of the Functional Strength Measure in children with UCP showed a similar ICC value (0.79) for the number of times that the child is able to lift a box for 30 seconds.[30] This study and ours show that we can reliably measure peaks of strength and use the maximum number of peaks as an outcome measure in a 30-second protocol. The dynamic protocol provides information regarding coordination and efficient contracting and relaxing of grip and pinch muscles and thus focuses on a different type of coordination between agonist and antagonist muscles than does the sustained protocol. However, more research regarding the added value of these static and dynamic motor fatigability protocols in the evaluation of upper limb impairments in children with UCP is necessary to determine how both types of motor fatigability impact the performance of different activities of daily living.

Performance Variability

SEMs and SDDs for static and dynamic motor fatigability are high (static motor fatigability: SEM for $F_{mean} = 0.23–2.13$ and SEM for SFI = 7.89–13.90; dynamic motor fatigability: $F_{mean} = 0.41–0.94$ and SEM for $N_{peaks} = 2.59–5.27$). These high SEMs and SDDs may be attributable to large within-participant variability due to the difficulties in coordination and selective motor control as a result of lack of central motor control (as discussed above) but also due to problems with motivation and concentration in children with UCP. The SEMs and SDDs are important values when determining the usability of an outcome measure in clinical practice to measure change over time or after therapy. A child with UCP needs to improve by more than the SDD to ensure that the change measured is not due to a measurement error. To date, effect sizes of therapies targeting static and dynamic motor fatigabilities are not available, making it difficult to estimate the average extent of change. Therefore, it is not possible to draw conclusions on the ability of these new static and dynamic motor fatigability outcome measures in children with UCP to measure progress over time. Recent studies using the SEM and SDD to investigate measurement error and interpretability in different upper limb strength tests and functional strength tests in children with UCP found similar SEMs and SDDs to our study.[17,29] These studies used 3- to 4-second maximum voluntary contractions. It appears advisable that both static and dynamic motor fatigability approaches be used as discriminative, but not as evaluative, measures due to the large SEMs and SDDs in comparable populations and measurement protocols.[17,29]

In addition to analyzing relative and absolute reliability in the total age group, subanalyses were performed by age range (ie, 6–11 years and 12–18 years). ICCs for the younger children were generally lower compared with the total group as well as the older children. However, the SEMs and SDDs were comparable between groups. These lower ICCs may be partly explained by the smaller sample size in the younger age group (n = 16–22), which decreased between-participant variability. Nonetheless, these results also indicate that more caution is needed when using the protocols in the younger children compared with older children.

Limitations

Although we included 50 children between 6 and 18 years old with a Manual Ability Classification System level range of I to III, not all children were able to perform the static or dynamic motor fatigability tasks, leading to smaller numbers of participants in the statistical analyses. More children had difficulties performing the tasks when using the pinch meter than with the grip meter. Furthermore, as might be expected, more children had difficulties performing the task with the more affected hand than with the less affected hand. The reasons for this inability to perform the tasks were twofold. First, some children were not able to produce enough strength to successfully perform the task because of muscle weakness; second, some had difficulties with contracting and relaxing their muscles, which was the case with the dynamic motor fatigability task. This indicates that in the dynamic motor fatigability tasks, other factors than just strength, such as motor coordination and selectivity, play an important role.

Furthermore, our included sample size of 50 children was less than anticipated based on the COSMIN criteria due to the COVID pandemic. However, on the basis of the studies of De Vet et al and Koo et al, our number of included children was sufficient to perform test–retest reliability research.[27–32] However, future research should investigate test–retest reliability with a larger number of participants to be able to consider manual impairment levels as well. In addition to this, the impact of the manual impairment level or cognition and motivation on the reliability of motor fatigability measures should be considered in future research.

On the basis of our outcomes, sufficient reliability can be assumed for F_{mean} and N_{peaks} in the first and last parts of the force-time curve. However, because we defined motor fatigability as "the magnitude or rate of change of motor performance on an objectively measured reference criterion after any type of voluntary activity or exercise," a calculation has to be performed to measure the change between the first and last parts of the force-time curve. Surakka et al and Schwid et al calculated a ratio between the first and last parts of the curve to describe this change.[19,20] We propose the use of such a ratio as well, based on F_{mean} and N_{peaks}, for the calculation of static and dynamic motor fatigability.

Furthermore, future research should include investigating other clinimetric properties of the motor fatigability protocols as well. On the basis of the present study, reliability is established; however, validity was not yet investigated. In a separate study, validity should be investigated by correlating the motor fatigability outcome measures with outcomes measures of maximal grip and pinch strength, unimanual capacity, and bimanual performance.

Most outcome measures for static motor fatigability and dynamic motor fatigability can be used reliably to investigate the presence and severity of motor fatigability in children with UCP. However, based on the SEMs and SDDs of these outcome measures, caution is needed in interpreting the results because of large measurement errors.

Author Contributions

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Ethics Approval

This research was approved by the Medical Ethical Committee of Hasselt University (CME2018/069), Maastricht University (2019–1168), and Teachers College, Columbia University (IRB 13–220).

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