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Reproducibility of Task-Oriented Bimanual and Unimanual Strength Measurement in Children with Unilateral Cerebral Palsy

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ABSTRACT

Aim: To examine reproducibility of the arm-hand strength measured while performing the bimanual crate task and the unimanual pitcher task. *Methods:* 105 children diagnosed with unilateral Cerebral Palsy, aged between 6 and 18 years, participated in this study. The test–retest reliability of the force generated during bimanual crate task and unimanual pitcher task of the Task-oriented Arm-hAnd Capacity instrument was investigated using intraclass correlation two-way random model with absolute agreement. The intraclass correlations were calculated for two age groups (6–12 and 13–18 years old). *Results:* The results showed good test–retest reliability for the crate and pitcher task with the non-affected hand for both age groups. The results of the pitcher task for the affected hand showed moderate test–retest reliability for both age groups. *Conclusion:* The Task-oriented Arm-hAnd Capacity instrument has moderate to good test–retest reliability. It is a simple and objective instrument to assess task-oriented strength in children with unilateral cerebral palsy.

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Cerebral palsy; upper extremity; muscle strength; task-oriented; test–retest reliability

Children with cerebral palsy (CP) often experience limitations in activities of daily living (ADL) due to impairments in motor function. Approximately 50% of the children with CP show more difficulties in the upper limb compared to lower limb (Song, 2014). Upper limb dysfunction is a common and disabling consequence of CP, which results in arm and hand problems (Boyd, Morris, & Graham, 2001). Besides spasticity, impaired selectivity, muscle weakness and impaired anticipatory control are major causes of poor arm-hand skill performance, which is defined as "the use of arm and hand during ADL tasks" (Lemmens et al., 2014). Furthermore, force accuracy and fine tuning of a movement is affected by a decrease in selectivity (Rameckers, 2009). Children with affected

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arm-hand skill performance experience difficulties with movements such as reaching, and grasping, lifting, and releasing objects (Chin, Duncan, Johnstone, & Graham, 2005).

Clinical assessments and interventions are often aimed at improving the function of the (most) affected hand (AH). However, children with unilateral CP show disuse of their AH, which is at least partly caused by development disregard (Zielinski, Steenbergen, Baas, Aarts, & Jongsma, 2014). The AH is more often used as assisting hand in bimanual tasks, which provokes the use of two hands. However, bimanual tasks are complex, because movements of both arms and hands must be coordinated in time and space to successfully complete the task (Greaves, Imms, Dodd, & Krumlinde-Sundholm, 2010). Most ADL tasks require bimanual use of the hands causing larger functional impairments in children with CP. An example of a bimanual task is pulling a cap from a pen, where one hand is used to stabilize or fixate the pen while with the other hand the cap is pulled off. This task ideally requires the use of the AH for stabilization and fixation (Smits-Engelsman, Klingels, & Feys, 2011). Both less- or non-affected hand (NAH) and AH need to use force to move (NAH) and stabilize (AH) the object. The weaker hand (AH) almost always determines function during a bimanual task (MacKenzie, 2007; Steenbergen, Charles, & Gordon, 2008).

Strength is commonly measured before and during therapy to determine the difference in strength generated in both arms. Most frequently maximal voluntary contraction of a muscle is measured using a grip and pinch strength measurement or isometric measurement of the arm muscles by hand-held dynamometry (HHD) (Hebert et al., 2011; Rameckers, Janssen-Potten, Essers, & Smeets, 2015). These measurements have proven to be reliable in children with CP (Hebert et al., 2011; Rameckers et al., 2015). However, rehabilitation therapy principles have been shifted towards functional therapy, wherein functional ADL tasks are trained during therapy. For this type of training it is essential for the therapist to detect potential causes of the problem during the performance of a specific ADL task. One of these potential problems is the strength generated while executing a specific ADL task, called task-oriented strength. Hence, it is important that the therapist can reliably measure strength while the child with CP is executing the specific ADL task of interest. Task-oriented measures are available for the lower limb in children with CP. Verschuren et al. (2008) operationalized this task-oriented strength measure of the lower limb by focusing on dynamic functional performance. This performance was assessed by determining the repetition maximum of functional exercises, such as the lateral step-up test and sit-to-stand test (Verschuren et al., 2008). A task-oriented strength measurement of the upper limb while executing an ADL task is not yet available.

In order to measure task-oriented upper limb strength in a relevant ADL task, we developed the Task-Oriented Arm hAnd Capacity (TAAC) instrument, which is part of a multi task-oriented device, named the Activities of daily life – test and training device (ADL-TTD). The TAAC instrument contains a sensor, which measures the force while the child lifts an ADL object. Lifting ADL objects are relevant tasks and common goals in children with CP, for example, lifting their school bag. For the TAAC instrument a crate and pitcher were developed as lifting objects.

This study focuses on the reproducibility of measurements of the TAAC instrument (de Vet, Terwee, Knol, & Bouter, 2006). The test–retest reliability of the crate and pitcher task of the TAAC instrument measured in children with unilateral CP in two age groups (6–12 and 13–18 years) will be investigated. We used these two age groups as due to puberty changes in muscle strength and body composition will occur (Loomba-Albrecht & Dennis, 2009). The children in the older age group are expected to have more strength than the children in the younger age group. The aims of this study are to examine (1) test–retest reliability of the bimanual crate task; (2) test–retest reliability of the unimanual pitcher task. It is hypothesized that the TAAC instrument has good test–retest reliability for both tasks in both age groups, indicated by intraclass correlations coefficient (ICC) equal or higher than 0.80.

Methods

Subjects

In this study data were obtained from upper limb intervention training camps, which the children attended in Adelante (Valkenburg, The Netherlands) and Teachers College, Columbia University (New York, USA), and a multicenter strength intervention study TOAST-CP (NL49818.015.14, METC nr 1431, nr 13-220). Children and/or parents signed an informed consent for this study. The data were gathered during baseline measurements. The children were included if they were between 6 and 18 years old. The children had to be diagnosed as CP and based on functional levels they were included if they had level I, II, or III of the Gross Motor Function Classification System (GMFCS) and Manual Ability Classification System (MACS) and level I, II or IIb of the Zancolli. The subjects were also analyzed in two age groups (6–12 and 13–18 years old), because of the change in muscle strength and body composition due to puberty (Loomba-Albrecht & Dennis, 2009).

Materials

Development TAAC

In collaboration with Instrument Development Engineering & Evaluation Maastricht, a prototype was developed in 2011 to measure task-oriented arm-hand strength aimed at uni- and bimanual lifting tasks. Two lift tasks were developed, a crate and pitcher task. In 2013, these tasks were tested for feasibility in children and adolescents ($n = 8$) with CP. Based on these results, the prototype and measurement protocol have been adapted to the current version in cooperation with Umaco B.V. In 2014, the inclusion of children and adolescents with CP started to investigate the reproducibility.

TAAC

The TAAC instrument (H.12EXTI09881; IDEE, Maastricht, The Netherlands) is an experimental prototype used for research. It is part of the device ADL-TTD, which is developed by Umaco B.V. The TAAC consists of a measuring unit and attachable objects, such as a crate (0.687 kg) (Figure 1A) and a pitcher (0.533 kg) (Figure 1B). By attaching the crate or pitcher to the measuring unit the provided force of the participant is measured during the task. The TAAC instrument allows pushing and pulling forces and registers force from –400 till 400 N, with an accuracy of 1 N. The TAAC instrument

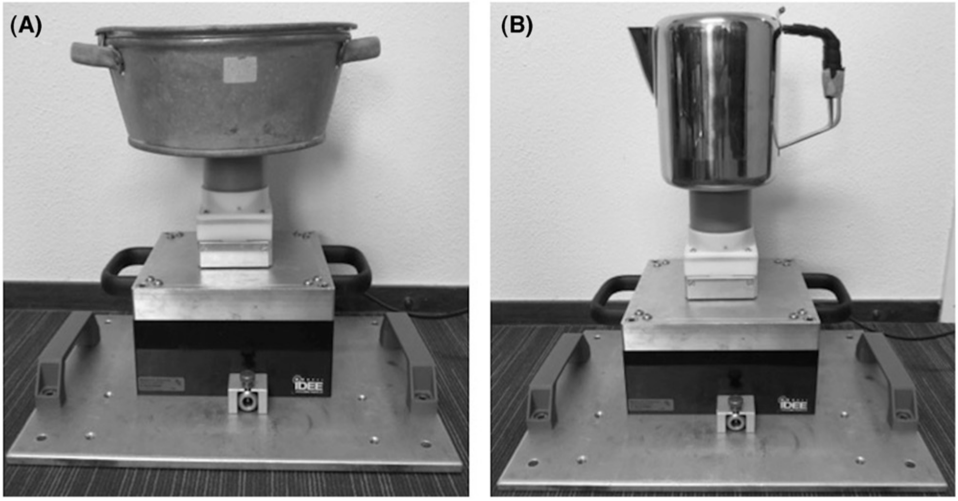

Figure 1. The TAAC instrument with the crate attached (A) and the pitcher attached (B).

is connected to a laptop with the associated software, SENSIT Test and Measurement. The program plots force produced by the participant and stores it for subsequent export to Excel. The task-oriented strength is expressed as peak force (N) lifted during the task. Before each measurement with a different task the TAAC needs to be calibrated.

Bimanual crate task

Participants are instructed to stand in front of the TAAC instrument, which is mounted on a table. During the bimanual measurement of the crate task the participant is required to pull the crate fixed to the device and hold it for 5 s. This is repeated for three trials, with a rest period of 30 s between trials. During the 5-s hold period the isometric force is measured. The crate must be pulled straight up and kept horizontal in its utmost position. The children have to gradually build up their force and then pull as hard as possible for 5 s. The force generated by the arms is measured. No compensatory strategies, such as keeping their arms by their side, leaning backwards or forwards or to a side were allowed. To prevent these strategies the assessor stood next to the participant to check and control the execution of the task. Two additional attempts were allowed if the first measurement failed. A measurement was considered a failure if the crate could not be held horizontal for the full 5 s or if compensatory strategies were used.

Unimanual pitcher task

The same protocol was used for the unimanual measurement with the pitcher. This measurement was performed with the NAH first and then with the AH.

Procedures

The measurement with the crate and pitcher task of the TAAC instrument was conducted twice to establish test–retest reliability. The measurements were performed during the baseline measurement of arm-hand intervention training camps or multicenter strength intervention study. There was at least 1-hour time interval between the two measurements. For the analysis the mean of the three maximum values were used, because it is more representative to the actual value, and minimizes various errors. For each child, all measurements were conducted by the same assessor. In total, three assessors conducted the measurements. The assessors all had a minimum of two years of experience conducting these measurements. During the measurements all researchers used the same standardized protocol, therefore the assumption was made that there is no influence of the assessor on the measurement.

Data analysis

First, the output was converted to kilograms (kg) and the peak values were detected using Matlab. Statistical analyses were performed using SPSS, version 23 (SPSS Inc., Chicago, IL, USA). Test–retest reliability of the TAAC instrument was investigated, using ICC two-way random model with absolute agreement ($ICC_{agreement}$). The $ICC_{agreement}$ were calculated for each age group. ICC values equal to or above 0.80 are considered to represent good reliability (Fleis & Cohen, 1973). Values between 0.40 and 0.79 represent moderate reliability and values less than 0.40 represent poor reliability (Fleis & Cohen, 1973). The ICC values were presented with the 95% confidence intervals (CIs), the ICC values were our threshold for an acceptable reliability.

The agreement between the measurements was displayed in Bland-Altman plots. To evaluate the level of agreement between the test and retest, limits of agreement (LOA) were used. Outliers, which are extreme values that deviate from the other values in the dataset, were detected and checked if they had any influence on the outcome. If not, they were included in all analyses.

Based on visual inspection of the Bland-Altman plots heteroscedasticity was checked. When the amount of error increased as the measured values increased, the data were suspected of being heteroscedastic. By calculating the Kendall's tau (τ) correlation between the absolute difference and the corresponding means, the degree of heteroscedasticity was measured. Data was denoted heteroscedastic when a positive $\tau > 0.1$ was found. When τ was <0.1 or negative, the data was denoted homoscedastic. If heteroscedasticity was present, the data were transformed by logarithms to the base 10 (Brehm, Scholtes, Dallmeijer, Twisk, & Harlaar, 2012). Thereafter, Kendall's τ was calculated again.

Furthermore, when the data showed no heteroscedasticity, agreement was determined using the standard error of measurement of agreement ($SEM_{agreement}$) and the smallest detectable difference (SDD). $SEM_{agreement}$ was calculated to determine variability between the measurements (de Vet et al., 2006). SDD was calculated to determine the range above which a clinically important change could be measured (de Vet et al., 2006). The SDDs were also expressed as a percentage of the average group value. The level of statistical significance was set at $p < 0.05$.

Results

In this study data of 105 children (TOAST-CP $n = 30$; intervention camp Adelante $n = 47$; intervention camp New York $n = 28$) diagnosed with unilateral CP was used.

The children were aged between six and 18 years. The subject characteristics are displayed in Table 1. In the 6–12-year-old group, 45 subjects were included (32 male and 13 female) with a mean age of 9 years and 6 months (SD = 1 years 11 months). In the 13–18-year-old group, 60 subjects were included (31 male and 29 female) with a mean age of 15 years and 5 months (SD = 1 years 7 months).

Not all 105 subjects completed all tasks, and these measurements are reported as missing. A schematic display of the number of subjects per task is shown in Figure 2.

Heteroscedasticity examination

Bland-Altman plots were created and Kendall's τ was calculated for all tasks and each age group (Figures 3–5, Table 2). Kendall's τ showed heteroscedasticity for the pitcher task of the AH in both age groups ($\tau = 0.188$ and $\tau = 0.120$, respectively).

Test–retest reliability of the crate task

The $ICC_{agreement}$ for the 6–12-year-old group ($n = 38$) was 0.955 (CI = 0.913 – 0.977), with a $SEM_{agreement}$ of 1.491 kg and a SDD of 4.132 kg (86%). The mean difference between the two measurements was 0.105 kg. The LOA were −13.880 kg and 13.670 kg, respectively. No outliers were identified based on the Bland-Altman plot (Figure 3A). The $ICC_{agreement}$ for the 13–18-year-old group ($n = 57$) was 0.846 (CI = 0.739–0.910), with a $SEM_{agreement}$ of 2.339 kg and a SDD of 6.483 kg (64%). The mean difference between the two measurements was 0.339 kg. The LOA were −11.343 kg and 12.021 kg. Four outliers were identified based on the Bland-Altman plot (Figure 3B).

Test–retest reliability of the pitcher task of the NAH

The $ICC_{agreement}$ for the 6–12-year-old group ($n = 40$) was 0.902 (CI = 0.815 – 0.948), with a $SEM_{agreement}$ of 0.557 kg and a SDD of 1.544 kg (58%). The mean difference

TABLE 1. Subject Characteristics.

	Total	Age group 6–12 years	Age group 13–18 years
Number of children	105	45	60
Mean age ± SD	12 years 11 months ±3 years 5 months	9 years 6 months ±1 years 11 months	15 years 5 months ±1 years 7 months
Gender			
Male	63	32	31
Female	42	13	29
Hemiparesis			
Left	57	23	34
Right	48	22	26
MACS			
I	27	11	16
II	53	25	28
III	25	9	16
GMFCS			
I	95	44	51
II	5	0	5
III	5	1	4
Zancolli			
I	48	24	24
II	46	21	25
IIb	11	0	11

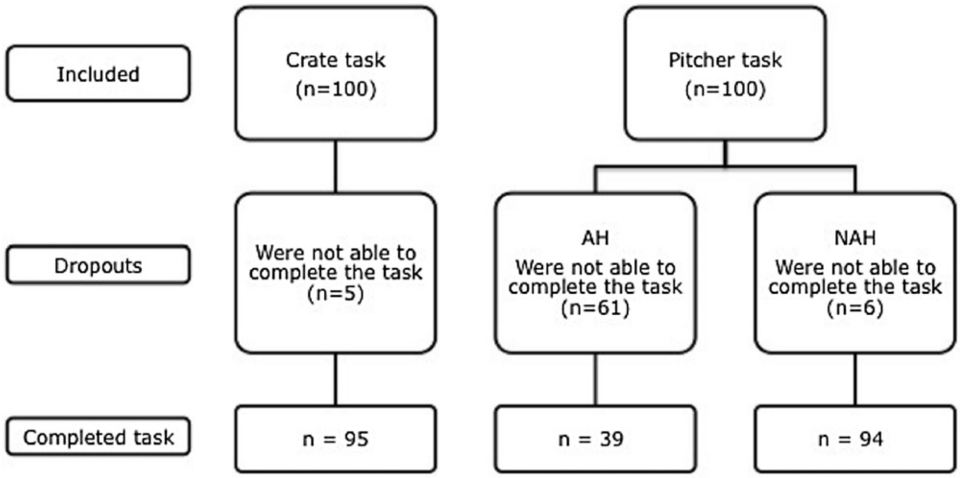

Figure 2. Schematic diagram of the number of subjects per task.

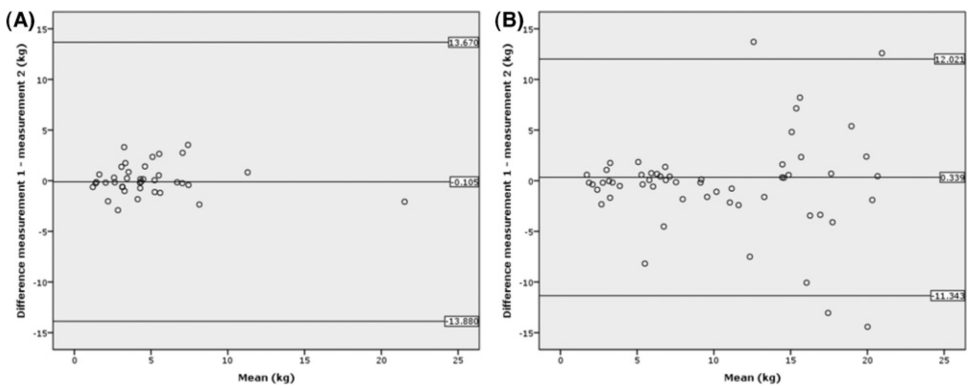

Figure 3. Bland-Altman plot for measurement 1 and measurement 2 of the crate task of the 6–12-year-old group (A) and the 13–18-year-old group (B). The middle line shows the mean difference between the two measurements, and the upper and lower lines indicate the limits of agreement. On the *X*-axes, the mean of both measurements of all subjects are displayed. On the *Y*-axes, the differences between both measurements of all subjects are displayed.

between the two measurements was 0.502 kg. The LOA were –3.990 kg and 2.987 kg, respectively. One outlier was identified based on the Bland-Altman plot (Figure 4A). The $ICC_{agreement}$ for the 13–18-year-old group ($n = 54$) was 0.853 (CI = 0.747–0.915), with a $SEM_{agreement}$ of 0.649 kg and a SDD of 1.799 kg (43%). The mean difference between the two measurements was 0.132 kg. The LOA were –3.450 kg and 3.185 kg, respectively. Three outliers were identified based on the Bland-Altman plot (Figure 4B).

Test–retest reliability of the pitcher task of the AH

The $ICC_{agreement}$ for the 6–12-year-old group ($n = 14$) was 0.586 (CI = –0.365 – 0.870), with a $SEM_{agreement}$ of 0.651 kg and a SDD of 1.803 kg (84%). The mean difference between the two measurements was 0.111 kg. The LOA were –1.871 kg and 2.093 kg, respectively. One outlier was identified based on the Bland-Altman plot (Figure 5A).

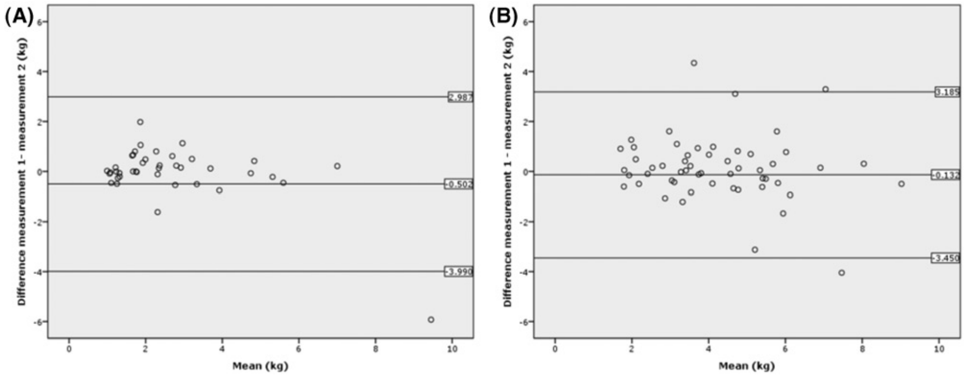

Figure 4. Bland-Altman plot for measurement 1 and measurement 2 of the pitcher task of the NAH of the 6–12-year-old group (A) and the 13–18-year-old group (B). The middle line shows the mean difference between the two measurements, and the upper and lower lines indicate the limits of agreement. On the *X*-axes, the mean of both measurements of all subjects are displayed. On the *Y*-axes, the differences between both measurements of all subjects are displayed.

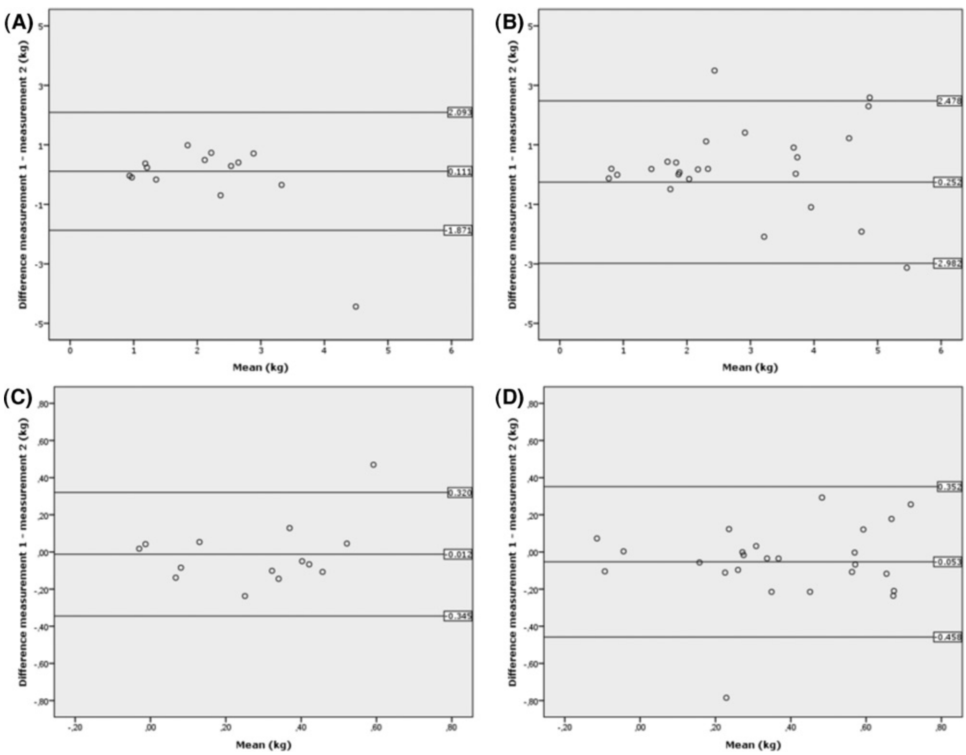

Figure 5. Bland-Altman plot for measurement 1 and measurement 2 of the pitcher task of the AH of the 6–12-year-old group (A) and the 13–18-year-old group (B), and the Bland-Altman plots for the log-transformed measurements for both age groups, respectively (C and D). The middle line shows the mean difference between the two measurements, and the upper and lower lines indicate the limits of agreement. On the *X*-axes, the mean of both measurements of all subjects are displayed. On the *Y*-axes, the differences between both measurements of all subjects are displayed.

TABLE 2. Heteroscedasticity Examination With the Original and Log-Transformed Measurements.

Task	n	Age group (years)	Mean (kg)	Absolute difference (kg)	τ correlation (absolute difference vs. mean)
Crate	38	6–12	4.823	0.105	0.700 ($p = 0.538$)
	57	13–18	10.197	0.339	0.018 ($p = 0.847$)
Pitcher NAH	40	6–12	2.397	0.502	0.012 ($p = 0.904$)
	54	13–18	4.220	0.132	−0.089 ($p = 0.343$)
Pitcher AH	14	6–12	2.150	0.111	0.188 ($p = 0.197$)
			0.280[a]	0.012[a]	−0.065[a] ($p = 0.655$)
	25	13–18	2.797	0.252	0.120 ($p = 0.400$)
			0.375[a]	0.053[a]	−0.013[a] ($p = 0.926$)

[a]Log transformed data.

After the logarithm transformation the mean difference between the two measurements was 0.012 kg. The LOA were −0.345 kg and 0.320 kg, respectively. One outlier was identified based on the Bland-Altman plot (Figure 5C). The $ICC_{agreement}$ for the 13–18-year-old group ($n = 25$) was 0.742 (CI = 0.419–0.886), with a $SEM_{agreement}$ of 0.708 kg and a SDD of 1.961 kg (70%). The mean difference between the two measurements was 0.252 kg. The LOA were −2.982 kg and 2.478 kg, respectively. Three outliers were identified based on the Bland-Altman plot (Figure 5B). After the logarithm transformation the mean difference between the two measurements was 0.053 kg. The LOA were −0.458 kg and 0.352 kg, respectively. One outlier was identified based on the Bland-Altman plot (Figure 5D).

Discussion

We examined test–retest reliability of the bimanual crate task and the unimanual pitcher task assessed with the TAAC instrument in children with unilateral CP in two age groups (6–12 years and 13–18 years). The results show that the crate task has a good test–retest reliability for the 6–12-year and 13–18-year-old group, with a moderate CI for the 13–18-year-old group. The results of the pitcher task with the NAH are similar to the results of the crate task. The test–retest reliability for both age groups (6–12 years and 13–18 years) was good, with a moderate CI for the 13–18-year-old group. The results of the pitcher task with the AH showed moderate test–retest reliability for the 6–12-year-old group and 13–18-year-old group, with a large CI in both groups. Despite the acceptable ICC values, the large CIs for each task and age groups show that there is room for improvement in the protocols.

Since this is the first task-oriented strength measurement of the upper extremity no comparable studies are available. The most comparable study is a study of Verschuren et al. (2008), that measured task-oriented strength in the lower extremity, but only interassessor reliability (ICC range 0.91–0.96) was investigated (Verschuren et al., 2008). There were no other comparable studies found that investigated a functional measurement or tasks. Therefore, the results of the TAAC will be compared to the results of HHD studies, since this is a standardized strength measurement. Several studies investigated the test–retest reliability of the HHD measurement of muscle groups in the lower extremity in children with CP (Berry, Giuliani, & Damiano, 2004; Crompton, Galea, & Phillips, 2007; De Groot et al., 2012; Taylor, Dodd, & Graham, 2004; Van Vulpen, De Groot, Becher, De Wolf, & Dallmeijer, 2013; Willemse et al., 2013). All studies found a good reliability for the strength measurement with ICCs ranging from 0.70 to 0.98

(Berry et al., 2004; Taylor et al., 2004; Willemse et al., 2013). In these studies no difference was made between the affected limb and non-affected limb. The ICCs found in this study for the crate task for both age groups (ICC = 0.846 and ICC = 0.955, respectively) are comparable to the ICCs found in the other strength studies. Two other studies that investigated the test–retest reliability of the HHD measurement of muscle groups in the lower extremity in children with CP did make a difference between the affected limb and non-affected limb (Crompton et al., 2007; Van Vulpen et al., 2013). The studies found ICCs with a large range for the more impaired leg from 0.401 to 0.990 (Crompton et al., 2007; Van Vulpen et al., 2013) and as well for the less impaired leg ranging from 0.257 to 0.845 (Crompton et al., 2007). De Groot et al. (2012) investigated the test–retest reliability of measuring lower limb strength with an isokinetic dynamometer in adults with CP and found ICC ranging from 0.74 to 0.88 for the more impaired leg and ICC ranging from 0.88 to 0.94 for the less impaired leg (De Groot et al., 2012). These results are similar to the results found in this study.

The SEM and SDD are important values for the clinical practice to inform about the measurement error for the scores of an individual and the amount of change that constitutes a real change. To be clinically useful, a measurement should only have a small amount of measurement error in detecting real change over time (Schreuders et al., 2000). When focusing on the SEM and SDD found in this study, it can be stated that a very large SDD was found for the crate task in the 13–18-year-old group. The large SDD may be the result of the large force variability at higher force levels especially in this age group (Smits-Engelsman, Rameckers, & Duysens, 2007). In the current study the children with the highest strength level showed the largest variability between the measurements contributing to a large SDD. Also, the results of the SDD for the crate task for the 6–12-year-old group were large. The reason could be a large variation in peak values (min peak value 0.90 and max peak value 22.56), wherein the children with the highest peak values had increased variability. This was also seen in the results of the pitcher task of the AH (min peak value 0.69 kg and max peak value 7.02 kg). The large values for the SDD imply that individual children, especially the ones who are only able to lift a low weight need to have quite large changes in measurement scores to be sure that a real change has occurred. Although the test–retest reliability for the tasks of the TAAC are moderate to good, the reliability for assessing changes in an individual child is less satisfactory than for a group of children (Schreuders et al., 2000).

This study has some limitations. In this study a heterogeneous population was used which might have resulted in higher ICC values compared to a homogeneous population. However, the population included is a good clinical representation of children with unilateral CP treated in the rehabilitation field. Furthermore, a high percentage (61%) of the children could not perform the pitcher task with the AH, because the pitcher could not be kept horizontal. This resulted in a small sample size compared to the pitcher task with the NAH and the crate task. The ICC is thus only based on the strength of children who have a stronger AH, indicating that the pitcher task can only be used in children with higher grip strength. For some children the pitcher was perhaps too heavy to lift (0.533 kg), therefore a pitcher of a lighter material can be made which could allow more children to lift the pitcher. Another possibility of not being able to perform the task might be due to the position of the elbow and wrist, which is standardized in the protocol. Some children could not perform the task in this manner. When more positions of the elbow and wrist are allowed, more children might be able to perform the task. Therefore, changes in the protocol have to be made allowing more movement of the elbow and wrist.

In this study we decided to analyze the children in two age groups. Age and MACS levels are frequently used to categorize children with CP. A very large sample size would be needed to classify the children with CP accordingly. We have chosen to only categorize on the basis of age and therewith accepted the variation in strength, based on MACS levels, within these age groups. The most effective method to divide children with CP into groups in the future would be cut off points per isometric strength level. Probably, a larger sample is needed.

Conclusion

The TAAC has a moderate to good test–retest reliability to measure task-oriented strength in children with CP on group level. However, for the individual child assessment the large SDD should be taken into account when interpreting changes in strength over time due to the large force variability. The crate task can be performed by most children, even children with a weaker AH. The actual pitcher task on the other hand cannot be performed by children with a weak AH, because the pitcher cannot be kept horizontal. Therefore, adjustments must be made to the TAAC that allows the strength to be measured even though the pitcher cannot be kept horizontal. Nonetheless, the TAAC meter is a simple and objective instrument to assess task-oriented unimanual and bimanual strength in children with unilateral CP. Further research is needed to improve the reproducibility and next to investigate construct validity and responsiveness of the TAAC.

Disclosure statement

No potential conflict of interest was reported by the authors.

About the Authors

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