Tyneside Pegboard Test for unimanual and bimanual dexterity in unilateral cerebral palsy: association with sensorimotor impairment

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ABBREVIATIONS

AHA	Assisting Hand Assessment
CHEQ	Children's Hand-use Experience Questionnaire
JTHFT	Jebsen-Taylor Hand Function Test
MACS	Manual Ability Classification System
TPT	Tyneside Pegboard Test

AIM We explored the psychometric properties of the recently developed Tyneside Pegboard Test (TPT) for unimanual and bimanual dexterity in children with unilateral cerebral palsy (CP) and investigated the impact of sensorimotor impairments on manual dexterity.
METHOD In this cross-sectional study, the TPT was assessed in 49 children with unilateral CP (mean age 9y 8mo, SD 1y 11mo, range 6–15y; 30 males, 19 females; 23 with right unilateral CP). All participants additionally underwent a standardized upper limb evaluation at body function and activity level. We investigated: (1) known-group, concurrent, and construct validity and (2) impact of sensorimotor impairments including spasticity, grip force, stereognosis, and mirror movements using analysis of covariance, Spearman's rank correlation (r), and multiple linear regression (R^2) respectively.
RESULTS TPT outcomes significantly differed according to the Manual Ability Classification System ($p<0.001$, known-group validity). Relationships were found between the unimanual TPT tasks and the Jebsen-Taylor Hand Function Test ($r=0.86$–0.88, concurrent validity). Bimanual TPT tasks were negatively correlated with the Assisting Hand Assessment, ABILHAND-Kids, and Children's Hand-use Experience Questionnaire ($r=-0.38$ to -0.78, construct validity). Stereognosis was the main determinant influencing all tasks ($p<0.001$, R^2=37–50%). Unimanual dexterity was additionally determined by grip strength ($p<0.05$, R^2=8–9%) and mirror movements in the more impaired hand ($p<0.05$, R^2=4–8%). Bimanual dexterity was also explained by mirror movements in the more impaired hand ($p<0.01$, R^2=10–16%) and spasticity ($p=0.04$, R^2=5%).
INTERPRETATION The TPT is a valid test to measure unimanual and bimanual dexterity in unilateral CP. The results further emphasize the importance of somatosensory impairments in children with unilateral CP.

Children with unilateral cerebral palsy (CP) experience sensorimotor impairments,[1] which are often more prominent in the upper limb than the lower limb.[2] Such sensorimotor impairments may compromise the development of manual dexterity,[3] the ability to perform fast coordinated movements,[4] which is crucial for performing everyday activities.

Recently, a quantitative tool was developed specifically for children with CP, to assess unimanual and bimanual dexterity, namely the Tyneside Pegboard Test (TPT).[5] The TPT is able to detect differences in unimanual and bimanual dexterity between typically developing children and those with unilateral CP.[5] However, whether the TPT can also discriminate between children with unilateral CP with different levels of manual ability, or known-group validity, has not yet been investigated. Moreover, concurrent validity and construct validity have not yet been fully examined.[5] Therefore, further investigation of the psychometric properties of this test is needed.

Furthermore, an in-depth investigation of the influence of sensorimotor impairments on unimanual and bimanual dexterity is warranted as the development of dexterity depends on the sensorimotor experiences in early life,[3] which are limited in children with unilateral CP. Thus far, it has been shown that unimanual dexterity is related to grip strength,[6] stereognosis,[6,7] and spasticity.[8] Other

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studies have shown that mirror movements may impact how children with unilateral CP use their more impaired hand during the performance of bimanual tasks.[9] Finally, exteroception has been shown as a determining factor of treatment outcomes of unimanual dexterity after constrained-induced movement therapy.[10] However, the extent to which all these sensorimotor impairments affect both unimanual and bimanual dexterity has not yet been studied. Investigating the combined impact of these sensorimotor impairments on unimanual and bimanual dexterity will deepen our insights into the factors underlying manual dexterity. Such insights will aid individual treatment planning by focusing on specific influencing factors.

In this study we aimed to examine psychometric properties of the TPT, establishing known-group validity, concurrent validity, and construct validity, and to investigate to what extent unimanual and bimanual dexterity are influenced by motor (spasticity, grip strength, and mirror movements) and somatosensory (exteroception and stereognosis) impairments. We hypothesized that unimanual and bimanual dexterity would be mostly influenced by grip strength and stereognosis, but bimanual dexterity would also be determined by the presence of mirror movements.

METHOD

Participants

This cross-sectional study included children with unilateral CP aged 6 to 15 years from the CP care programme of the University Hospitals Leuven, Belgium. For inclusion, children had to be: (1) capable of comprehending the test instructions and cooperative in completing the tasks and (2) able to grasp and stabilize an object with the more impaired hand (≥4 on the Modified House Functional Classification[11]). Children were excluded if they had received botulinum neurotoxin A to the upper limb in the 6 months before testing or had undergone upper limb surgery in the 2 years before testing. All parents gave written consent and children assented, in accordance with the Declaration of Helsinki. The study was approved by the Ethics Committee Research UZ/KU Leuven (S55555 and S56513).

Assessments

We used the TPT (Newcastle University, Newcastle upon Tyne, UK) to measure unimanual and bimanual dexterity,[5] where nine pegs were moved from one board to an adjacent board as quickly as possible (Fig. 1). A lower score on the TPT presents a faster and better performance.[5] Normative data for 974 participants from 4 to 80 years were available. Moreover, moderate test–retest reliability (intraclass correlation coefficient 0.74–0.91) and concurrent validity with the Purdue pegboard test (r=−0.61) were established in these population norm participants as well as construct validity in children with unilateral CP (Assisting Hand Assessment [AHA], r=0.63–0.69; ABILHAND, r=0.62–0.65).[5] Unimanual tasks were performed first, in order of decreasing peg sizes (large, medium, small), using

What this paper adds

- The Tyneside Pegboard Test is valid for measuring unimanual and bimanual dexterity in unilateral cerebral palsy.
- Children with poorer manual ability show worse unimanual and bimanual dexterity.
- Stereognosis is the main predictor of both unimanual and bimanual dexterity.
- Stronger mirror movements in the more impaired hand result in worse bimanual dexterity.

the less impaired hand. A more detailed description of the three unimanual tasks (UNI_{large}, UNI_{medium}, and UNI_{small}) can be found in Figure 1a–c. If the child could not perform the task with a specific peg size, further testing with smaller peg sizes was not pursued to prevent frustration. Completion time was electronically collected and outputted through custom-written software.[5] In the bimanual condition, only large pegs were picked up one by one with one hand, passed through a hole in a Perspex screen to the other hand, and placed in the adjacent board. For this study, completion time in both directions (Fig. 1d from the more impaired to the less impaired hand [$BI_{MI–LI}$] and Fig. 1e from the less impaired to the more impaired hand [$BI_{LI–MI}$]) was used in the statistical analysis.

As with other dexterity tests,[12] we implemented a maximum time of completion based on the collected data, for each child that was unable to perform a task or performed slower than this proposed threshold. For each of the five tasks, mean+2SD was calculated. The maximum time was set at 116.38s, 94.51s, and 146.63s respectively for UNI_{large}, UNI_{medium}, and UNI_{small}. For $BI_{MI–LI}$ the threshold was 75.48s and for $BI_{LI–MI}$ it was 167.10s.

Known-group validity investigates a test's ability to differentiate between different groups of a specific characteristic[13] and is assessed using the Manual Ability Classification System (MACS).[14] To assess concurrent validity, children performed the Jebsen-Taylor Hand Function Test (JTHFT), measuring unimanual dexterity during six timed tasks, where a lower score (shorter time) indicated better performance.[12] Additionally, we included the AHA, the ABILHAND-Kids questionnaire, and the Children's Hand-use Experience Questionnaire (CHEQ) for construct validity. The AHA evaluates how children with unilateral CP spontaneously use their more impaired hand during bimanual activities, resulting in 0 to 100 logit-based AHA units.[15] Next, parents completed the ABILHAND-Kids questionnaire, indicating whether 21 predominantly bimanual daily activities were 'impossible', 'difficult', or 'easy', and converted to a logit score from −6 to 6.[16] The CHEQ is a 29-item online form (http://www.cheq.se/) assessing the child's experience when using the more impaired hand in bimanual daily activities. Its three subscales measure: (1) which hand is used (CHEQ-grip), (2) time needed (CHEQ-time), and (3) whether the child feels 'bothered' by the bimanual activity (CHEQ-feeling). The raw score is transformed to a logit scoring from 0 to 100.[17] A higher score on these three measurements

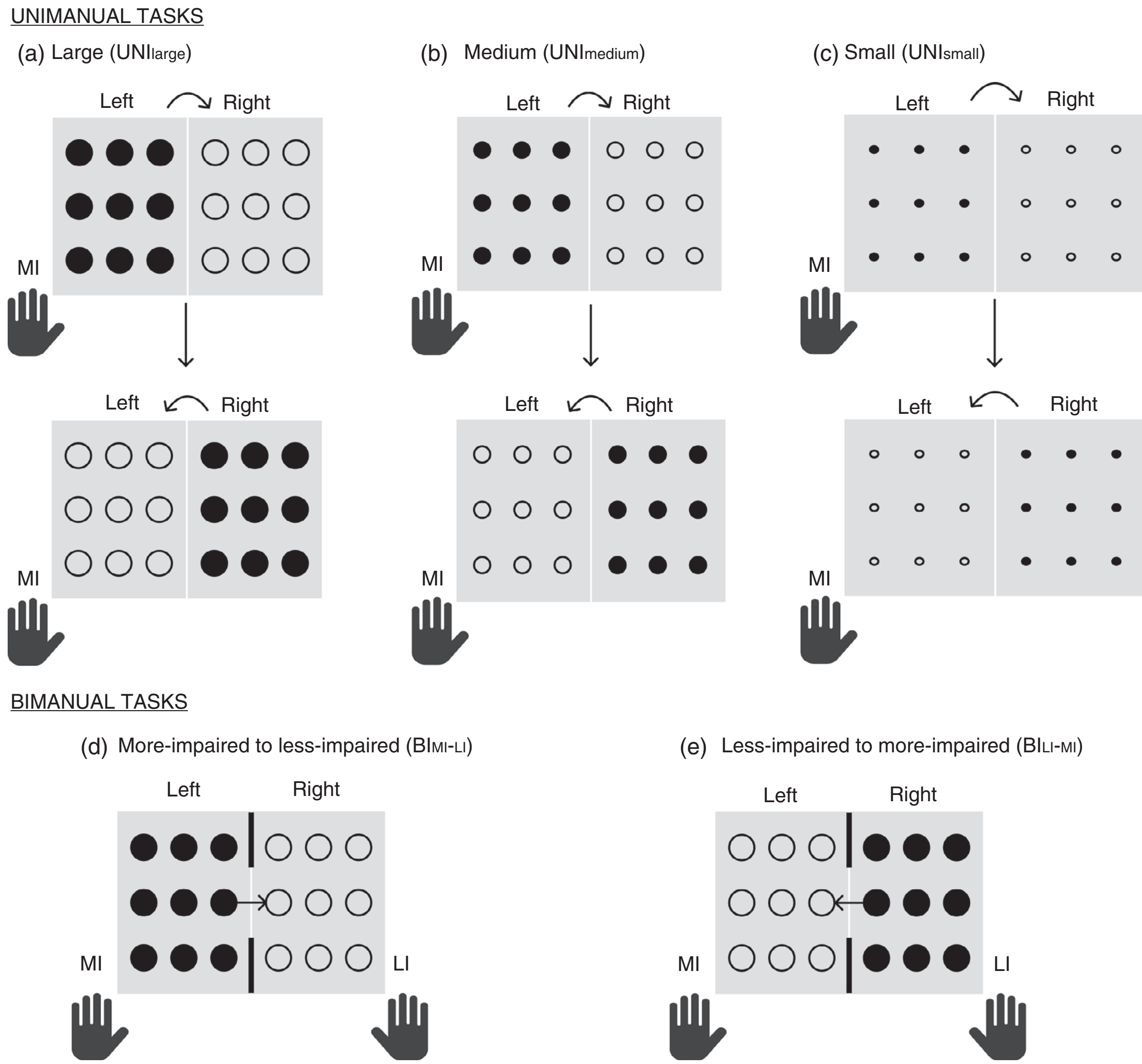

Figure 1: Overview of unimanual and bimanual Tyneside Pegboard Test tasks.

indicates better performance.[12,15–17] Psychometric properties were established for all these assessments.[12,15–17]

To investigate factors influencing dexterity, several impairments were assessed. Spasticity was measured with the Modified Ashworth scale, providing a score of 0 to 4 for each muscle group (shoulder adductors and internal rotators, elbow flexors and pronators, wrist flexors, finger flexors, and thumb adductors), resulting in a total score from 0 ('no spasticity') to 28 ('highest spasticity').[18] Grip strength was measured using a Jamar dynamometer (Sammons Preston, Rolyan, Bolingbrook, IL, USA). The average of three maximum contractions was used for further analysis.[18] Sensory function included exteroception and stereognosis,[1] during which the child's vision was occluded. Exteroception was determined with a reliable clinical test by lightly touching the index finger of the child three times. The child needed to indicate every time the touch was felt, and was graded 0 for absent, 1 for impaired (touch was not felt in one or more attempt[s]), or 2 for intact (all three attempts correct).[18] Stereognosis was assessed through tactile identification of six familiar objects.[18] A score ranging from 0 to 6 was given, according to the correct number of identified objects. In addition, mirror movements, which are involuntary movements in one hand that mirror voluntary movements in the other hand,[19] were quantitatively assessed using the Windmill Task (Behavioural Science Institute, Nijmegen, the Netherlands),[20] which comprises a small windmill connected to an active and passive grip-force transducer. The child had to hold both transducers and repetitively squeeze in the active transducer to make the windmill turn. Mirroring activity was registered through the passive transducer. We calculated, per hand, mirror movements-similarity (i.e. similarity between the two hand movements), and mirror movements-intensity (i.e. strength of the mirroring activity). When the mirror movements-similarity was at least

0.30, children were classified as having mirror movements.[20] A detailed explanation of the assessment and mirror movements quantification can be found elsewhere.[20]

Statistical analysis

General characteristics of the participants were collected such as age, sex, and side of unilateral CP, and data quality was verified using outlier detection (value >1.5 interquartile range). When an outlier was detected, clinical reasoning and statistical analyses without the outliers were performed to determine whether they should be removed or not. As the Shapiro–Wilk tests showed no normal distribution of the TPT parameters, non-parametric tests were used for construct and concurrent validity. For known-group validity and influencing factors, one-way analysis of covariance (ANCOVA) and multiple regression with backwards elimination were used, and normal distribution of the residuals was checked and confirmed for each fitted model.[21]

An ANCOVA was used to investigate the known-group validity of the TPT between MACS levels with age as covariates. If the interaction between age and MACS was not significant, the model with the main effects was retained. Bonferroni-corrected post hoc comparisons were computed to investigate differences between the three MACS levels, using a corrected *p*-value for multiple comparison (α=0.05). Effect sizes were calculated using partial η squared (η_p^2) and interpreted as small (0.01–0.06), medium (0.06–0.14), and large (>0.14).[22] Effect sizes of post hoc comparisons were calculated according to Cohen's *d* and interpreted as small (0.2–0.5), medium (0.5–0.8), and large (>0.8).[23] Spearman's rank correlation coefficients were used to assess construct and concurrent validity. Correlation coefficients were interpreted as no or little correlation (<0.3), low (0.3–0.5), moderate (0.5–0.7), high (0.7–0.9), and very high (>0.9).[24]

Finally, we investigated the influence of sensorimotor impairments on unimanual and bimanual dexterity using a multiple regression model with backwards elimination. As only one independent variable should be included per 10 participants,[25] simple linear regression analyses for the continuous variables (age, stereognosis, spasticity, grip strength, and mirror movements) and univariate analysis of variance (ANOVA) for the categorical variable (exteroception) were used to reduce the number of independent variables. Variables with p>0.05 on all tasks were not included in multiple regression analysis. Multicollinearity between the independent variables was investigated using the variance inflation factor, of which a value above 10 indicates multicollinearity.[26] SPSS Statistics version 26.0 (IBM, Armonk, New York, USA) was used for all statistical analyses.

RESULTS

Participants

In total, 49 children with unilateral CP (mean age 9y 8mo, SD 1y 11mo, range 6–15y; 30 males; 23 with right unilateral CP) were included and classified according to their manual ability level (12 in MACS level I, 17 in MACS level II, and 20 in MACS level III). Two children in MACS level II were outliers (child 1 on all TPT tasks and child 2 on $BI_{LI–MI}$). These were the only two children in MACS level II who received the implemented threshold because of inability or difficulty with performing the TPT. However, these children were still included in the analysis, assuring that the whole spectrum of children in MACS level II was involved. According to mirror movements-similarity, 29 children in our sample had mirror movements (18 children showed mirror movements in both hands, five children only in the more impaired hand, and six children in the less impaired hand). More information about the distribution of the mirror movements characteristics can be found in Figure S1 (online supporting information). One child did not perform the bimanual tasks of the TPT because of technical problems, whereby only her unimanual TPT tasks were included. In case of missing data for the sensorimotor assessments, children were not included in the multiple linear regression analysis of those tasks, resulting in 43 children for the unimanual TPT tasks and 42 children for the bimanual TPT tasks. In total, 15 children received the implemented threshold, because they were unable to perform the task and/or because they performed the task at a slower pace than the threshold. A detailed overview of this implemented threshold according to the MACS levels is provided in Tables S1 and S2 (online supporting information).

Psychometric properties

Known-group validity

The interaction between MACS level and age was not significant for any task (p=0.24–0.56) and omitted from further analysis. A main effect of MACS levels was found with large effect sizes (p<0.001, η_p^2>0.35) during unimanual (UNI_{large}: η_p^2=0.37; UNI_{medium}: η_p^2=0.43; UNI_{small}: η_p^2=0.57; Fig. 2) and bimanual tasks ($BI_{MI–LI}$: η_p^2=0.37; $BI_{LI–MI}$: η_p^2=0.35). Post hoc comparisons showed that children in MACS level III performed significantly worse than those in MACS levels I (p<0.001) and II (p<0.05) for all TPT tasks. No significant differences were found between MACS levels I and II, except for the UNI_{small} task (p=0.04). An overview of the results is provided in Figure 2 and Table S3 (online supporting information).

Concurrent validity

High positive correlations were found between all three unimanual tasks and the JTHFT (UNI_{large}: r=0.88; UNI_{medium}: r=0.86; UNI_{small}: r=0.87; p<0.001).

Construct validity

A high negative correlation was found between the AHA and both bimanual tasks ($BI_{MI–LI}$: r=−0.78, p<0.001; $BI_{LI–MI}$, r=−0.76, p<0.001; Table 1). The ABILHAND-Kids questionnaire correlated moderately with both bimanual tasks ($BI_{MI–LI}$: r=−0.64, p<0.001; $BI_{LI–MI}$: r=−0.68, p<0.001; Table 1), while for the CHEQ, mainly low

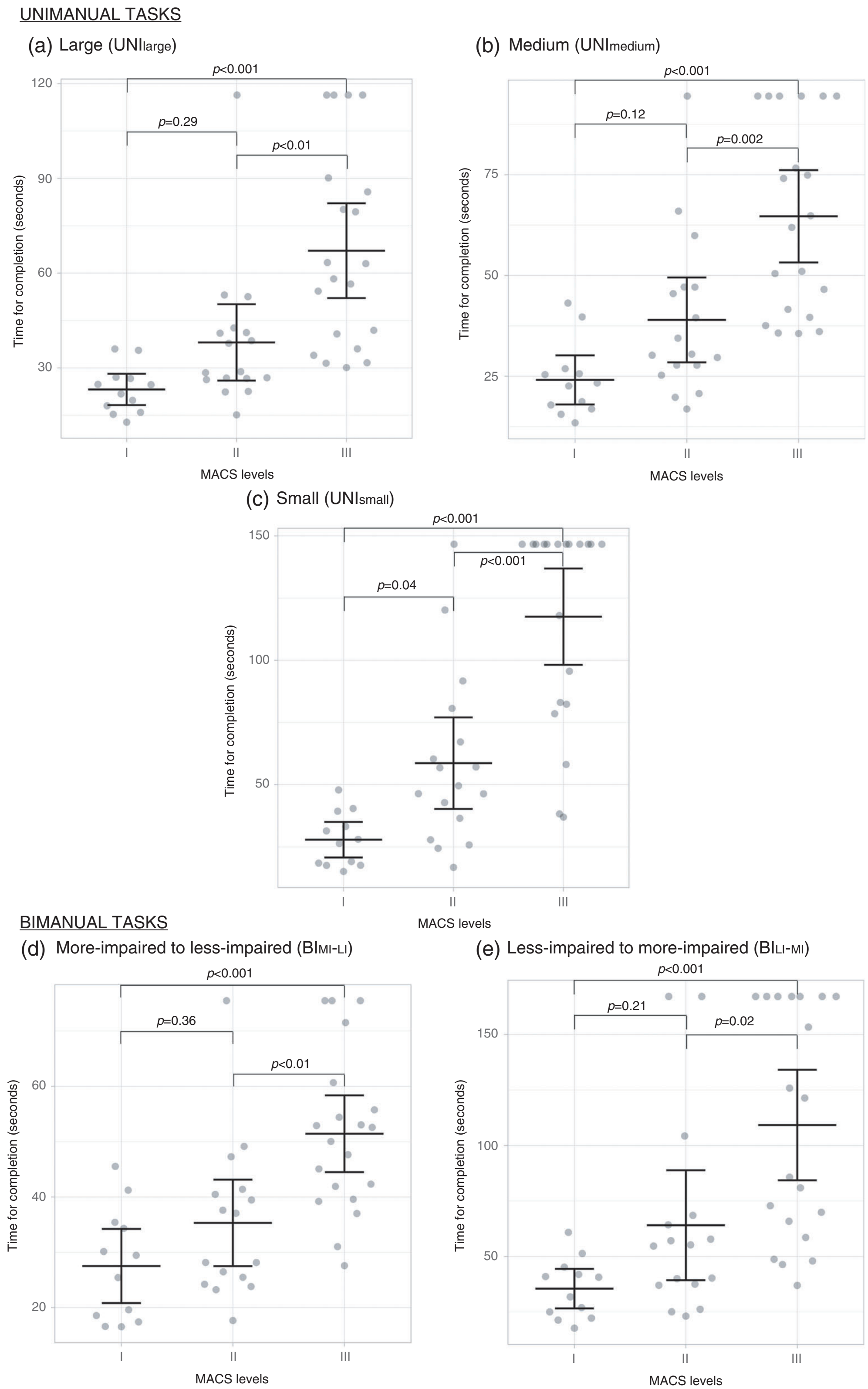

Figure 2: Single data points of different unimanual and bimanual Tyneside Pegboard Test tasks across the three Manual Ability Classification System levels. *P*-values in bold type are statistically significant ($p<0.05$).

negative correlations were found with both bimanual tasks (r=−0.38 to −0.52), $p<0.01$; Table 1).

Influence of sensorimotor impairments on unimanual and bimanual dexterity

On the basis of simple linear regressions, the following variables were selected for the multiple regression analysis: stereognosis ($p<0.001$, R^2=0.30–0.46), spasticity ($p<0.05$, R^2=0.04–0.15), grip strength ($p<0.001$, R^2=0.25–0.40), and mirror movements-intensity in the more impaired hand ($p<0.05$, R^2=0.11–0.30). An overview of the individual relationships, simple linear regression analysis, and univariate ANOVA between the TPT tasks and the factors can be found in Tables S4 and S5 (online supporting information). For all multiple regression analyses, the variance inflation factor ranged from 1.08 to 1.46, indicating low multicollinearity between the independent variables. Correlation coefficients and scatter plots between the retained predictors can be found in Figure S2 (online supporting information).

In the multiple regression, stereognosis was the main factor explaining both unimanual and bimanual dexterity ($p<0.001$, R^2=0.37–0.50). Unimanual dexterity was additionally determined by grip strength (UNI_{medium}: $p<0.01$, R^2=0.09; UNI_{small}: p=0.03, R^2=0.09) and by mirror movements-intensity in the more impaired hand ($UNI_{large:}$ p=0.02, R^2=0.08; UNI_{small}: p=0.04, R^2=0.04). Bimanual dexterity was also determined by mirror movements-intensity in the more impaired hand ($BI_{MI–LI}$: $p<0.01$, R^2=0.16; $BI_{LI–MI}$: $p<0.01$, R^2=0.10) and by spasticity ($BI_{MI–LI}$: p=0.04, R^2=0.05). A more detailed overview of the results is provided in Table 2.

DISCUSSION

This study established psychometric properties of the TPT, namely known-group, concurrent, and construct validity in children with unilateral CP. Furthermore, stereognosis was found to be the main factor explaining unimanual and bimanual dexterity, followed by grip strength for unimanual dexterity and mirror movements-intensity in the more impaired hand for bimanual dexterity.

First, we investigated psychometric properties of the TPT. Our results showed that the TPT can discriminate between manual ability levels in children with unilateral CP, establishing known-group validity. The TPT tasks discern MACS level III from other levels very well. Between MACS levels I and II, a significant difference was only found in the unimanual task with small pegs. During the analysis, two participants in MACS level II were identified as outliers. These two participants had more difficulties with performing the tasks, resulting in the implementation of the threshold. When removing these outliers from the analysis, only the results of the UNI_{small} between MACS levels I and II changed to a non-significant result. This is not unexpected, since the two children with the most impaired performance in the MACS II group were left out of the analysis. However, excluding these children may potentially have biased our results as we would not include the whole spectrum of children with a MACS level II classification, thus compromising the generalizability of our results. Subsequently, we opted to report the results of the whole group. Still, an overview of the results without these outliers is provided in Table S6 (online supporting information).

Second, we established concurrent validity of the unimanual TPT tasks by showing agreement with the commonly used JTHFT. Nevertheless, the TPT has the advantages of measuring both unimanual and bimanual dexterity electronically and being easily adapted using the different peg sizes. Moreover, norm values are available.[5] We found that children with a lower score on bimanual assessments performed slower on the TPT, establishing construct validity. Slightly higher correlations were found between the TPT and the AHA and ABILHAND-Kids compared with the findings of Basu et al.[5] This might be explained by the fact that in this study children with more severely impaired hand function could also still be included because of the implementation of the thresholds. Next to this, the TPT correlated higher with the AHA than with the CHEQ, indicating that the CHEQ in particular measures a different aspect of bimanual performance. The CHEQ evaluates the perceived abilities of the more impaired hand during bimanual daily life activities.[27] In contrast, the AHA focuses more on the observed spontaneous use during bimanual play, and specifically evaluates grasping abilities during task performance (e.g. grasps, grip stability, readjust grasp, etc.),[15] which may explain the higher correlation with the TPT.

Third, results from the univariate linear regression were in line with our hypothesis and showed moderate to high association between stereognosis and grip strength with all TPT tasks. Multiple regression analysis identified stereognosis as the main predictor of both unimanual and bimanual dexterity. This is in line with literature showing that

Table 1: Spearman's rank correlation coefficients between the bimanual TPT tasks and AHA, ABILHAND, and CHEQ

TPT	AHA, r (p)	ABILHAND, r (p)	CHEQ, r (p)		
			Grip	Feeling	Timing
$BI_{MI–LI}$	−0.78 (<0.001)	−0.64 (<0.001)	−0.44 (0.002)	−0.41 (0.005)	−0.39 (0.007)
$BI_{LI–MI}$	−0.76 (<0.001)	−0.68 (<0.001)	−0.38 (0.008)	−0.48 (<0.001)	−0.52 (<0.001)

$p<0.05$ was considered statistically significant. TPT, Tyneside Pegboard Test; AHA, Assisting Hand Assessment; CHEQ, Children's Hand-use Experience Questionnaire; $BI_{MI–LI}$, bimanual task from the more impaired to the less impaired hand; $BI_{LI–MI}$, bimanual task from the less impaired to more impaired hand.

Table 2: Overview of final models of the multiple regression analysis on unimanual and bimanual dexterity

TPT tasks	R^2 final model	Retained predictors	p	Individual R^2	B (95% CI)	β
Unimanual dexterity						
UNI_{large}	0.46	Stereognosis	<0.001	0.38	−7.19 (−10.43 to −3.95)	1.60
		Mirror movements-intensity in the more impaired hand	0.02	0.08	0.20 (0.03–0.67	0.08
UNI_{medium}	0.59	Stereognosis	<0.001	0.50	−6.52 (−9.37 to −3.68)	1.41
		Grip strength	<0.01	0.09	−2.03 (−3.44 to −0.61)	0.70
UNI_{small}	0.62	Stereognosis	<0.001	0.49	−12.34 (−17.91 to −6.77)	2.75
		Grip strength	0.03	0.09	−3.24 (−6.15 to −0.34)	1.44
		Mirror movements-intensity in the more impaired hand	0.04	0.04	0.29 (0.01–0.57)	0.14
Bimanual dexterity						
$BI_{MI–LI}$	0.61	Stereognosis	<0.001	0.40	−3.55 (−5.30 to −1.81)	−0.45
		Mirror movements-intensity in the more impaired hand	<0.01	0.16	0.14 (0.04–0.23)	0.34
		Spasticity	0.04	0.05	1.49 (0.11–2.87)	0.25
$BI_{LI–MI}$	0.47	Stereognosis	<0.001	0.37	−12.27 (−18.30 to −6.24)	2.98
		Mirror movements-intensity in the more impaired hand	<0.01	0.10	0.42 (0.11–0.74)	0.16

TPT, Tyneside Pegboard Test; R^2 final model, degree of variance of the TPT task that is explained by the retained predictors; Individual R^2, degree of variance of the TPT tasks that is explained by one specific retained predictor; B, unstandardized coefficient; CI, confidence interval; β, standardized coefficients; UNI_{large}, unimanual task with large pegs; UNI_{medium}, unimanual task with medium pegs; UNI_{small}, unimanual task with small pegs; $BI_{MI–LI}$, bimanual task from the more impaired to the less impaired hand; $BI_{LI–MI}$, bimanual task from the less impaired to more impaired hand.

stereognosis is highly correlated with the unimanual JTHFT.[6] Owing to an impaired stereognosis, the ability to make a mental representation of the object during the TPT task might be affected, which has an influence on the anticipatory control to adapt the correct grip force with timed accuracy.[8] Hence, because of an impaired stereognosis, the child may have to rely more on visual feedback, which could slow down the sensorimotor feedback,[28] resulting in a slower performance in the TPT tasks. Also, grip strength has been shown to be an important predictor of unimanual dexterity.[6] In this study, grip strength was identified as an additional explanatory factor of the more difficult unimanual tasks with medium and small pegs. Also, the univariate correlations between grip strength and unimanual dexterity were high. These results emphasize the importance of both grip strength and somatosensory function for unimanual dexterity. Stronger mirror movements in the more impaired hand determined a small part of the variance in the unimanual tasks with large and small pegs. This is an unexpected result, as mirror movements are suggested to mostly have an effect on bimanual tasks.[9] A possible explanation is the presence of ipsilateral corticospinal tract projections from the dominant hemisphere to the more impaired hand in children with mirror movements.[29] It has been shown that children with ipsilateral and bilateral corticospinal tract projections have worse unimanual dexterity compared to those with a contralateral corticospinal tract.[30] Another explanation could be that children with a weak hand function use the mirror movements in the more impaired hand, as support to perform the unimanual tasks.[31] Furthermore, stronger mirror movements in the more impaired hand were found to be the second largest determinant of the bimanual TPT tasks. Surprisingly, mirror movements-intensity in the less impaired hand and mirror movements-similarity in both hands showed no to low correlations with the bimanual TPT tasks. Zielinski et al. found the same trend for bimanual performance, where higher correlations were found with mirror movements-intensity compared with mirror movements-similarity in the more impaired hand.[31] Different neuropathological mechanisms of mirror movements could possibly explain the different outcomes between both hands.[32] Both the presence of ipsilateral corticospinal tract projections and the lack of interhemispheric inhibition have been put forward to explain the occurrence of mirror movements in children with unilateral CP.[32] Future research is warranted to unravel the complex relationship between mirror movements and their underlying neuropathological mechanisms and how this affects bimanual dexterity in children with unilateral CP. Lastly, spasticity had a minor significant contribution for the bimanual task performed from the more impaired to the less impaired hand. Spasticity is most often present in the distal muscle groups of the upper limb such as the wrist flexors and forearm pronators.[1] Hence, increased spasticity in these muscle groups may compromise a good orientation of the peg through the hole, impeding the peg transfer from the more impaired towards the less impaired side.

Some limitations of this study also need to be addressed. First, some clinical factors were measured with an ordinal score and qualitative scale, such as exteroception and spasticity. Nevertheless, reliability of both measurements has been shown previously.[18] Second, in this study we specifically aimed to investigate the impact of sensorimotor impairments. However, our results show that the variability in manual dexterity cannot be fully explained by these sensorimotor impairments alone. Other factors, such as vision, cognition, and motor planning may further influence the performance of these tasks. More research with a larger sample size is needed to elucidate which factors fully explain the variability of manual dexterity. Third, owing to missing data in the sensorimotor impairments, not all children could be included in the final multiple regression analysis. Nevertheless, as the pattern of missing data was random, the analysis remained unbiased.[33] Lastly, we implemented a maximum time in case children with a more severely impaired hand function (MACS level III) struggled to complete the most difficult tasks. As no maximum time was determined before the assessment, we decided to set a threshold based on the mean+2SD, resulting in thresholding the data of children who performed the task slower than that cut-off or who were not able to perform that task. As a result, children with a more severely impaired hand function could also still be included, since not being able to perform the tasks also provided information on the manual dexterity level of these children. Hence, in accordance with the JTHFT, we propose implementing a threshold value for future administration with the TPT, limiting frustration in children with a more impaired hand function and preventing empty data. Nevertheless, because of this implementation, 12 of the 20 children in MACS level III received this threshold, resulting in a low number of children with unchanged data (eight children) for the task UNI_{small} compared with the other MACS levels (MACS level I: 12 children; MACS level II: 16 children). Hence, the results of the current study need to be validated in a new study sample including the implementation of our proposed threshold. On the basis of our data and those of Basu et al.,[5] we propose 120s as a threshold for UNI_{large}, UNI_{medium}, and $BI_{MI–LI}$ for future testing, and 150s for UNI_{small} and $BI_{LI–MI}$, as these tasks are perceived as more difficult in children with unilateral CP.

Nevertheless, our study suggests that both sensory (i.e. stereognosis) and motor (i.e. grip strength) functions are important factors for manual dexterity, corresponding to the suggestion that these are both key ingredients for upper limb intervention in children with unilateral CP.[34] Although motor-based training forms the typical approach to improve functionality, somatosensory function should also be taken into account. A recent study of survivors of adult stroke has already shown beneficial results on unimanual capacity after intensive somatosensory discrimination training during which texture discrimination, proprioception, and stereognosis were trained.[35] The effect of an integrated sensorimotor training programme on unimanual and bimanual dexterity in children with unilateral CP still warrants further investigation.

CONCLUSION

This study established known-group, construct, and concurrent validity of the TPT assessment in children with unilateral CP. The main determinant of both unimanual and bimanual dexterity was stereognosis. Unimanual dexterity was additionally determined by grip strength and mirror movements-intensity in the more impaired hand, and bimanual dexterity by mirror movements-intensity in the more impaired hand and spasticity. For future purposes, we recommend using a threshold to minimize frustration and prevent empty data.

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DATA AVAILABILITY STATEMENT

All data concerning this study is available within the manuscript. Detailed data is available upon request to the first author.

SUPPORTING INFORMATION

The following additional material may be found online:

Figure S1: Distribution of the mirror movement characteristics in both hands.

Figure S2: Pearson's correlation coefficients with scatter plots between retained predictors of the multiple regression analysis.

Table S1: Missing and descriptive statistics of the outcome measures for TPT tasks

Table S2: Overview of children who received the identified threshold for each TPT task as a function of the MACS levels

Table S3: Descriptive statistics and the one-way ANCOVA results of the main effect of MACS levels on TPT outcome, with age as a covariate

Table S4: Pearson's correlation coefficients between TPT tasks and nine clinical factors

Table S5: Simple linear regression analysis between TPT tasks and eight clinical factors and univariate ANOVA between TPT tasks and exteroception

Table S6: Descriptive statistics and the one-way ANCOVA results of the main effect of MACS levels on TPT outcome, without outliers

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