ORIGINAL REPORT

HAND IMPAIRMENTS AND THEIR RELATIONSHIP WITH MANUAL ABILITY IN CHILDREN WITH CEREBRAL PALSY

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Objective: **To study hand impairments and their relationship with manual ability in children with cerebral palsy.**
Design: **Cross-sectional survey.**
Patients: **A total of 101 children with cerebral palsy (mean age 10 years, age range 6–15 years) were assessed.**
Methods: **Three motor and 3 sensory impairments were measured on both hands. Motor impairments included grip strength (Jamar dynamometer), gross manual dexterity (Box and Block Test) and fine finger dexterity (Purdue Pegboard Test). Sensory impairments included tactile pressure detection (Semmes-Weinstein aesthesiometer), stereognosis (Manual Form Perception Test) and proprioception (passive mobilization of the metacarpophalangeal joints). Manual ability was measured with the ABILHAND-Kids questionnaire. The relationship between hand impairments and manual ability was studied through correlation coefficients and a multiple linear forward stepwise regression analysis.**
Results: **Motor impairments were markedly more prevalent than sensory ones. Gross manual dexterity on the dominant hand and grip strength on the non-dominant hand were the best independent predictors of the children's manual ability, predicting 58% of its variance.**
Conclusion: **Hand impairments and manual ability are not related in a predictable straightforward relationship. It is important that, besides hand impairments, manual ability is also measured and treated, as it is not simply the integration of hand functions in daily activities.**

Key words: cerebral palsy, hand, motor skills disorders, sensation disorders, disability evaluation.

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Cerebral palsy (CP), the most prevalent form of physical disability in children, commonly affects the brain structures responsible for skilled hand movements (1). The severity and type of hand impairments (i.e. motor or sensory impairments) vary widely according to the time of appearance, the location and the degree of cerebral damage. There is therefore a need to quantify hand impairments in the various types of children with CP (i.e. hemi-, di-, and tetra-plegics).

Hand sensorimotor impairments are generally thought to be largely responsible for the difficulty experienced in daily activities (2). Based on this assumption, many conventional treatments endeavour to reduce hand impairments assuming that this will result in a higher capacity in managing manual activities (3), i.e. manual ability (4). However, the International Classification of Functioning, Disability and Health (ICF) (5) conceptualizes hand impairments and manual ability as different dimensions of functioning that are not necessarily related in a predictable straightforward way. Empirical investigation of the relationship between hand impairments and manual ability in children with CP is therefore required in order to confirm or refute the clinical assumption that a reduction in hand impairments will necessarily result in a higher manual ability.

The relationship between hand impairments and manual ability has rarely been examined in children with CP. This probably lies in the fact that there is a lack of appropriate instruments for measuring the ability of the children to use their hands in daily activities (4, 6). While most hand impairments can be measured with physical units (e.g. grip strength can be measured in Newtons), manual ability is a capacity concealed within a person or a child and cannot be directly measured (7). Nevertheless, such capacity can be inferred from a child's performance in manual activities as determined by questionnaires. In an early study (4), the ABILHAND-Kids questionnaire was developed as a measure of manual ability in children with CP. The questionnaire assesses the parents' perception of a child's difficulty in performing manual activities and the score is transformed into a unidimensional and linear measure of manual ability via the Rasch measurement model (8).

The few studies investigating the relationship between hand impairments and manual ability indicate that motor functions such as grip strength, dexterity and spasticity appear to correlate relatively well with manual ability (9–10), while sensory functions, especially tactile sensibility, do not have a decisive influence on the hemiparetic hand's involvement in bimanual performance (10). However, these studies are restricted to small samples of children with hemiplegia (9–10).

The objectives of this study were to quantify hand impairments in various types of children with CP and investigate their relationship with manual ability as measured with the ABILHAND-Kids questionnaire.

METHODS

Subjects

The study was authorized by the ethics committee of the Université catholique de Louvain, Faculty of Medicine in Brussels, Belgium. The

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definition adopted for selecting children with CP was "all non-progressive but often changing motor impairment syndromes secondary to lesions or anomalies of the brain arising in the early stages of its development" (11). A total of 101 children with CP (mean age 10 years, age range 6–15 years; 58% boys; 91% perinatal injury) were recruited through 7 centres specialized in CP and were assessed by the same examiner. All children selected in the study were older than 6 years to make sure that their manipulative skills in activities of daily living were mature and presented no major intellectual deficit (IQ ≥ 60). The subjects were classified according to their school education programme, with reference to the decree organizing specialized education in Belgium published on 3 March 2004. Among our sample of patients, 41 were following mainstream education, one stayed at home and 59 were following a special education programme adapted to educational needs of either children with physical impairments (n = 52), children with learning disabilities (n = 6) or children with mild mental retardation (n = 1). The sample description is shown in Table I.

Assessment of hand impairment

The children were tested individually in a quiet room and were instructed how to perform each test. Three motor and 3 sensory impairments were assessed on both hands, starting with the dominant hand (DH). Handedness was determined by writing hand preference.

Motor impairments included grip strength, gross manual dexterity and fine finger dexterity. Grip strength was measured with a Jamar dynamometer (Therapeutic Equipment Corporation, Clifton, New Jersey, USA) according to the procedure described by Mathiowetz et al. (12). The grip strength score was determined as the average of the maximal force exerted on the dynamometer across 3 trials. Gross manual dexterity was measured with the Box and Block Test (13) according to the procedure of Mathiowetz et al. (14). The gross manual dexterity score was determined as the maximum number of blocks transported individually from one compartment of a box to the other in one min. Fine finger dexterity was measured with the Purdue Pegboard Test (15) (Lafayette Instrument Model 32020, Sagamore, USA) according to the procedure described by Mathiowetz et al. (16). The fine finger dexterity score was determined on 3 trials as the average number of pegs picked up from a cup and placed into the holes of a board within 30 sec.

Table I. *Sample description (n = 101)*

Characteristics	n
Age (years), mean (range)	10 (6–15)
Sex	
Male	59
Female	42
Handedness	
Right	51
Left	49
Ambidextrous	1
School education	
Mainstream	41
Type 1: Mild mental retardation	1
Type 4: Physical handicap	52
Type 8: Learning disabilities	6
Home	1
Type of CP	
Topographical classification	
Tetraplegia	31
Diplegia	20
Hemiplegia	
Right	25
Left	25
Symptomatic classification	
Spastic syndrome	81
Dyskinetic syndrome*	5
Ataxic syndrome	2
Mixed syndrome	13

*Athetosic, dystonic, and choreic movements.

Sensory impairments included tactile pressure detection, stereognosis, and proprioception. Tactile pressure detection was measured at the tip of the index finger with a Semmes-Weinstein aesthesiometer (17) (Lafayette Instrument Company, Loughborough, UK) according to the procedure described by Bell-Krotoski (17). The tactile pressure detection threshold was determined as the force required to bend the thinnest filament the blindfolded children could feel. Stereognosis was measured with the Manual Form Perception Test as modified by Cooper et al. (18). The stereognosis score was determined as the number of objects out of 10 correctly identified by touch by the blindfolded children. Proprioception was measured by passively moving the metacarpophalangeal joints of the thumb and the index finger according to the procedure of Cooper et al. (18). The proprioception score was determined as the number of joint movement directions the blindfolded children correctly identified out of 10 trials (5 for the thumb and 5 for the index finger).

Manual ability assessment

Manual ability was measured with the ABILHAND-Kids questionnaire (4). This questionnaire measures the child's "capacity to manage daily activities requiring the use of hands and upper limbs, whatever the strategies involved" (7). Twenty-one mostly bimanual activities were rated by the children's parents on a 3-level scale (0: impossible, 1: difficult, or 2: easy) by providing their child's perceived difficulty in performing each activity. The parents were asked to complete the questionnaire by estimating their child's ease or difficulty in performing each activity, when the activities were done: (*i*) without other technical or human help (even if the child actually uses help in daily life), (*ii*) irrespective of the limb(s) actually used to do the activity, and (*iii*) whatever the strategy used (any compensation is allowed). Activities not attempted in the last 3 months were not scored and were encoded as missing responses. As reported in a previous study (4), the ordinal total scores obtained on the ABILHAND-Kids questionnaire were subsequently transformed into linear measures according to the Rasch model (8). The manual ability measures were expressed in "logits", a probabilistic unit defined as the natural logarithm of the odds of success of a child to an activity (i.e. the pass/fail probability ratio). This unit is constant throughout the measurement scale. At any level of the measurement scale, a 1-logit difference in children's ability implies a constant ratio of their odds of success ($e^1 = 2.71$) to any given activity; a 2-logit difference always represents the odds of success in a ratio of $e^2 = 7.39$, and so on. Consequently, the linear measures obtained by the Rasch model can be used to compare quantitatively the ability of different children with CP.

Statistical analysis

Motor scores were converted into standardized scores (z-scores) according to normative data available in the literature (12, 16) and norms established in our laboratory (19) (for gross and fine manual dexterity). This procedure determines the extent to which a CP child deviates from normal given his or her age, gender, and handedness and allows all scores to be expressed on a common z-score scale. Motor functions were considered as significantly impaired when the z-score was lower than –2.

Sensory scores were not z-transformed since the normative data were not normally distributed despite various attempts of data normalization. Sensory raw scores were therefore compared with those of age- and sex-matched healthy children measured in our laboratory. The tactile pressure detection of the controls, expressed as the median (interquartile range), were 67.7 (27.5–67.7) mg on the dominant hand (DH) and 67.7 (27.5–166) mg on the non-dominant hand (NDH). On both hands, the controls showed a median (interquartile range) of 10 (10–10) objects and joint movement directions correctly identified for respectively stereognosis and proprioception. Sensory functions were considered as significantly impaired when the raw score was lower than the fifth percentile of the distribution observed for the controls (i.e. 166 mg for tactile pressure detection; 9 objects correctly identified for stereognosis; 7 joint movement directions correctly identified for proprioception).

Correlation coefficients were used to determine the linear association between each hand impairment and manual ability. All hand impairments significantly related to manual ability were subsequently included in a multiple linear forward stepwise regression to identify the combination of hand impairments that best predicted manual ability measures. The forward stepwise method consists: (*i*) in selecting the independent variable (i.e. a hand impairment) that produces the best prediction of the dependent variable (i.e. manual ability), (*ii*) in selecting the independent variable that adds the next largest amount of information, (*iii*) in verifying the usefulness of the first selected variable after the addition of the second one, (*iv*) in removing the first variable if it does not remain useful, and (*v*) in repeating this process until adding or removing variables does not significantly improve the prediction of the dependent variable. The adjusted coefficient of determination which considers the number of selected variables was used to avoid the overestimation of the real predictive capacity of the regression equation. The combined influence of such hand impairments on manual ability has been tested using a Kruskal-Wallis test. The alpha level of significance was fixed at 0.001 for all statistical tests to minimize type 1 errors.

RESULTS

Hand impairments in each type of CP are sorted by decreasing prevalence in Table II. Overall, hand impairments were less prevalent on the DH than on the NDH. Motor impairments were markedly more prevalent than sensory impairments for all CP types. Children with tetraplegia were all bilaterally impaired in gross manual and fine finger dexterity, with more then 60% presenting a significant impairment in grip strength on either hand. Almost all the children with diplegia were bilaterally impaired in fine finger dexterity, with slightly more than half of them showing bilateral impairments in gross manual dexterity and grip strength. Hemiplegic children also presented motor impairments in their non-paretic hand, especially in fine finger dexterity. The distribution of motor impairments in children with CP relative to norms is described in Fig. 1. Impairments of dexterity are larger and sparser than of grip strength, indicating that children with CP are more severely affected in their dexterity, with a wider distribution. Though less prevalent than motor impairments, sensory impairments were sometimes found in children with CP. Overall, tactile pressure detection and stereognosis of both hands were significantly impaired in our sample compared with age- and sex- matched healthy children ($p < 0.001$). In contrast, proprioception was not significantly impaired.

The manual ability measures of children with CP are presented briefly here, as they were extensively reported in a previous study (4). The manual ability was not significantly different in diplegic and hemiplegic children (*t*-test, $p = 0.45$). Tetraplegic children displayed a significantly lower manual ability (mean: –0.35 logits, standard deviation (SD) 2.45) than other CP types (mean: 2.02 logits, SD 1.91), indicating that their odds of success to any particular activity is on average more than 10 (i.e. $e^{2.37}$) times lower.

Correlation coefficients between hand impairments and manual ability are presented in Table III. On both hands, manual ability was significantly but moderately correlated with motor

Table II. *Prevalence of hand impairments according to cerebral palsy types*

Impairments	Total sample (%) $n = 101$	Tetra-plegia (%) $n = 31$	Di-plegia (%) $n = 20$	Hemi-plegia (%) $n = 50$
Dominant hand				
Fine finger dexterity	86	100	90	76
Gross manual dexterity	57	97	50	36
Grip strength	47	61	55	34
Tactile pressure detection	21	32	15	16
Stereognosis	20	39	10	12
Proprioception	4	6	0	4
Non-dominant hand				
Fine finger dexterity	97	100	90	98
Gross manual dexterity	83	100	65	80
Grip strength	73	77	50	80
Tactile pressure detection	33	32	20	38
Stereognosis	38	42	15	44
Proprioception	15	13	0	20

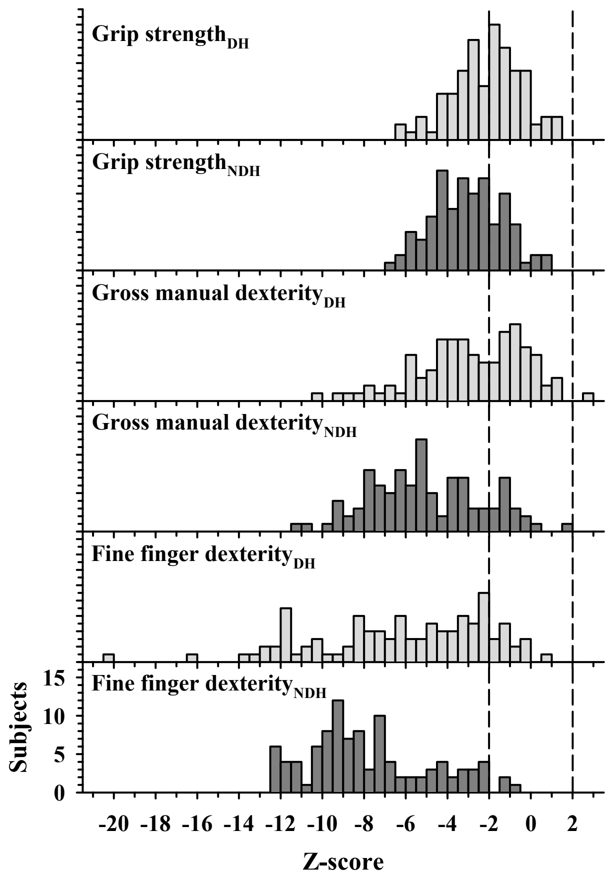

Fig. 1. Z-score distributions of grip strength, gross manual dexterity and fine finger dexterity computed in children with CP for both the dominant hand (DH, in pale grey) and the non-dominant hand (NDH, in dark grey). A z-score range between –2 and 2 was considered as not significantly different from normal.

Table III. *Relationship between hand impairments and manual ability*

Hand impairments	Dominant hand		Non-dominant hand	
	Statistic*	*p*-value	Statistic*	*p*-value
Grip strength	$R = 0.52$	< 0.001	$R = 0.56$	< 0.001
Gross manual dexterity	$R = 0.67$	< 0.001	$R = 0.66$	< 0.001
Fine finger dexterity	$R = 0.61$	< 0.001	$R = 0.45$	< 0.001
Tactile pressure detection	$\rho = 0.11$	0.273	$\rho = -0.13$	0.191
Stereognosis	$\rho = 0.49$	< 0.001	$\rho = 0.48$	< 0.001
Proprioception	$\rho = 0.15$	0.129	$\rho = 0.26$	0.010

*Reported statistics are *R* for Pearson correlations, and ρ for Spearman correlations.

impairments and stereognosis, while no significant relationship was found with tactile pressure detection and proprioception. Gross manual dexterity presented the highest correlation with manual ability on both hands, followed by fine finger dexterity on the DH and grip strength on the NDH. As shown in Table IV, the multiple linear forward stepwise regression showed that gross manual dexterity on the DH was the strongest predictor of manual ability accounting for 44% of the variance. Grip strength on the NDH, the second best independent predictor of manual ability, accounted for only a further 14% of the variance, leading to a total adjusted coefficient of determination of 0.58. Adding other hand impairments improved the prediction of manual ability measures by less than 5%. The regression equation obtained by the forward stepwise method was the following: manual ability = 4.42 + 0.51 * GMD_{DH} + 0.56 * GS_{NDH}. For instance, a child with CP with an impaired gross manual dexterity on the DH (e.g. z-score = –4.56) but a normal grip strength on the NDH (e.g. z-score = –1.13) would have a higher predicted manual ability than another child with CP with more severe impairments in both gross manual dexterity on the DH (e.g. z-score = –7.58) and grip strength on the NDH (e.g. z-score = –4.67). In our example, the first and the second child would have a predicted manual ability of 1.46 and –2.06 logits, respectively, while their actual manual ability measures are 0.18 and –2.07 logits. There is a difference between the predicted and the actual manual ability measures as the regression equation only partially explains the manual ability measures, namely 58% of their variance.

Cumulative hand impairments, i.e. gross manual dexterity on the DH and grip strength on the NDH, were significantly related to a decrease in manual ability (Kruskal-Wallis test, $p < 0.001$). In our sample, children without impairment in these functions ($n = 18$) had the highest manual ability measures (fig. 2).

Table IV. *Multiple linear regression (forward stepwise method)*

Hand impairments selected in the model	R	R^2	$R^2_{adjusted}$	Delta $R^2_{adjusted}$
GMD_{DH}	0.67	0.45	0.44	0.44
GMD_{DH} + GS_{NDH}	0.77	0.59	0.58	0.14

R: correlation coefficient; R^2: determination coefficient; GMD_{DH}: gross manual dexterity on dominant hand; GS_{NDH}: grip strength on non-dominant hand.

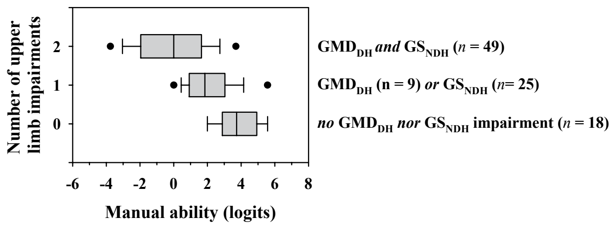

Fig. 2. Box plots showing the manual ability measure distributions of children with CP according to the presence of a significant impairment (z-score lower than –2) of gross manual dexterity on the dominant hand (GM_{DH}) and grip strength on the non-dominant hand (GS_{NDH}). Solid dots indicate the 5% and 95% outliers; vertical bars outside the box indicate the 10% and 90% limits; box indicates the 25% and 75% limits (i.e. the interquartile range); and the vertical line inside the box indicates the median of the distributions.

Children with one significant impairment, either in gross manual dexterity on the DH ($n = 9$) or in grip strength on the NDH ($n = 25$), presented a slightly lower manual ability. The 49 children significantly impaired in both gross manual dexterity on the DH and grip strength on the NDH had the lowest manual ability measures, with a median measure of 0 logit equivalent to the average item difficulty of the ABILHAND-Kids questionnaire.

DISCUSSION

Hand impairments and their relationship with manual ability were investigated in 101 children with CP. Motor impairments, especially fine finger dexterity, were markedly more prevalent than sensory ones. On both hands, manual ability was significantly but moderately correlated with motor impairments and stereognosis, while no significant relationship was found with tactile pressure detection and proprioception. Gross manual dexterity on the DH and grip strength on the NDH were the best independent predictors of manual ability, however, predicting only 58% of its variance.

All hand impairments were less prevalent on the DH than on the NDH, confirming that children with CP have developed their handedness on the less affected side. Bilateral hand impairments were, however, observed for all CP types including diplegic and hemiplegic children. This finding is in agreement with previous studies (18, 20), which also report that the non-paretic hand of children with hemiplegia was significantly impaired, although to a lesser extent than the paretic hand. Motor impairments were more important than sensory ones in all types of children with CP. The most prevalent motor impairments were observed in fine finger dexterity. This cannot be attributed solely to grip strength impairments as these are less common. In fact, fine finger dexterity requires the integrity of the corticospinal tract, a structure frequently damaged in CP (20). The finding that fine finger dexterity was more frequently impaired than gross manual dexterity is also supported by previous studies in monkeys (21–22), showing that early corticospinal tract lesions irremediably disrupted fine finger dexterity, while a noteworthy recovery could be observed in gross manual dexterity. Significant impairments were observed in tactile pressure detection and stereognosis, confirming previous reports made on smaller samples (10, 18, 23–24). In contrast, proprioception was rarely affected in our CP sample, a finding not supported by other studies (23, 25) which failed to compare CP scores with those of controls while, according to our observations, proprioception improves in some healthy children up to 9 years old.

Tactile pressure detection and proprioception were not related to manual ability, as reported in a previous study on children with hemiplegia (10). It can be hypothesized that tactile pressure detection and proprioception were not sufficiently impaired in children with CP to affect the achievement of manual activities in a significant way (26–27). One sensory hand function that could be interesting to explore in children with CP is the tactile spatial resolution (i.e. perception of spatial features of objects and surfaces). Unlike tactile pressure detection, which largely reflects the integrity of peripheral nerve fibres (28), tactile spatial resolution involves the cortical integration of peripheral impulses (24). Tactile spatial resolution seems therefore more appropriate for the detection of cortical lesions, such as those observed in CP than tactile pressure detection (10). However, the role of tactile spatial resolution in executing motor functions and its influence on manual ability remain to be empirically tested in children with CP. Contrary to tactile pressure detection and proprioception, stereognosis was moderately related to manual ability. As active in-hand manipulation is more efficient in object identification than passive manipulation (i.e. objects are stationary put on the palm or are passively rotated over the surface of the skin) (29), stereognosis impairments might result from motor deficits rather than from real sensory impairments, hence supporting its relationship with manual ability. However, the causality of any relationship cannot be asserted.

Gross manual dexterity on the DH and grip strength on the NDH were the combination of hand functions that best predicted the manual ability of children with CP. This finding emphasizes that manual activities typically require the co-operation of both hands, which tend to be specialized for different functions (30–31). For instance, when we remove the lid from a jar or we button up a shirt, the NDH holds the object in a stable position while the DH acts upon it. Hence, the NDH plays a postural role in stabilizing the grasped object and at the same time provides a spatial reference frame into which the DH manipulates the object (31). However, saying that the NDH offers stability does not mean that the hand is immobile. On the contrary, the NDH ensures a plastic stabilization and therefore produces steady states that are subject to frequent alterations (30). For instance, in handwriting, the pen cannot be dexterously manipulated by the DH if the page is not stabilized and periodically re-positioned by the NDH so that the position and orientation of the page always remain appropriate to the DH action. It is therefore fallacious to differentiate the roles of the hands in terms of a stationary NDH and a mobile DH as mobility is undeniably required on both hands. This is consistent with our finding that gross manual dexterity presents the highest correlation with manual ability on both hands, followed by fine finger dexterity on the DH and grip strength on the NDH. In other words, the achievement of manual activities requires: (*i*) a highly dexterous DH to perform both fine and gross manipulations, and (*ii*) a strong and an enough dexterous NDH to ensure an adjustable stabilization of the objects.

Although the combination of hand impairments was significantly related to a decrease in manual ability, it predicted only 58% of the variance in manual ability measures. This finding supports the theoretical standpoint of the ICF that hand impairments and manual ability are not related in a predictable straightforward way (5). The therapist cannot assume that the reduction in hand impairments will result in a corresponding higher manual ability. Consequently, interventions focused only on hand impairments reduction may be questionable, especially as it is more important for the child to manage daily activities to be autonomous than to have "normal" hand functions (32). A comprehensive intervention should always endeavour to improve manual ability by training the child to perform the daily activities that are limited (33). The therapist should teach the child to optimize the use of his or her existing hand functions in the management of meaningful activities. Teaching adapted strategies should also be an important part of the hand rehabilitation as they can help the child compensating for the hand impairments (34). They are particularly useful when the reduction in hand impairments is hardly possible or is impossible (35). The therapist should, so far as possible, enable the child to have an active role in finding adaptive strategies for the achievement of daily activities (32). Indeed, teaching the child to find self-initiated solutions is important, as the child will continually be confronted with new challenges (32). The success of adapted strategies will depend on the integrity of both the DH and the NDH, but also on children's motivation, adaptability, emotional control, cognitive skills, familial and social environment. Parents of children with CP may also adapt their habits to facilitate some activities (e.g. by not over-tightening a bottle) or, on the contrary, may inhibit some activities to prevent risk or save time (4). So, as suggested by the ICF (5), several contextual factors of the person (e.g. cognitive status, motivation, adaptability) and the environment (e.g. health services, financial support, parents' habits) may facilitate or hinder the achievement of manual activities and thus should be considered in the rehabilitation process (36–37). For instance, motivation (i.e. a facilitating personal factor) may compensate a child's hand impairments by learning adapted strategies such as breaking down a bimanual activity into several unimanual sequences; low incomes of the child's parents (i.e. a hindering environmental factor) may prevent the child from benefiting from assistive devices that are expensive but effective in reducing manual ability limitations. The therapist should attempt to identify the contextual factors that are crucial for the child's manual ability (38) and to find what can be changed within these contextual factors to facilitate the achievement of daily activities (39). However, some contextual factors are hardly modifiable (e.g. the attitudes of the society, the parents' incomes, the community facilities) (40). When planning the rehabilitation intervention, it is thus necessary to address the contextual factors that are easily modifiable and that have the greatest potential to improve the child's manual ability (40). Future research is, however, required to identify which contextual factors really contribute to the achievement of manual activities.

The present study was limited by its cross-sectional nature and in that causality could not be determined by using correlation coefficients or multiple linear regression analysis. As a result, it cannot be stated that 58% of the variance observed in manual ability measures result directly from hand impairments. Prospective studies would therefore be useful to determine how changes in hand impairments influence child's manual abilities. This study has, however, the merit of stressing the importance of treating and measuring manual ability *per se* as it is not simply the integration of hand functions in daily activities. It does not mean that interventions intended to reduce hand impairments are useless. However, improving a child's manual ability is of great importance and should be a major goal in the rehabilitation of children with CP.

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The ABILHAND-Kids questionnaire and its administration instructions can be downloaded from www.rehab-scales.org in English, French and Dutch. The website also allows raw scores to the ABILHAND-Kids questionnaire to be converted into a linear measure of manual ability, according to the Rasch model.

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