**Development and validation of the Both Hands Assessment for children with bilateral cerebral palsy**

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Running head: Both Hands Assessment: development and validation

**ABSTRACT**

**Aims:** To develop a hand function test for children with bilateral cerebral palsy (CP) measuring bimanual performance, including quantification of possible asymmetry of hand use. **Method:** The Both Hands Assessment (BoHA) content was developed through adaptation of the Assisting Hand Assessment (version 5.0). Data from 171 children with bilateral CP, 22-months to 13 years olds (75 females; mean age: 6 years and 6 months) classified at Manual Ability Classification System (MACS) levels I-III, was entered into Rasch measurement model analyses to evaluate internal scale validity and aspects of reliability. **Results:** Sixteen items (11 unimanual and 5 bimanual) exhibited evidence for good internal scale validity and item and person reliability when analysed separately for children with asymmetric or symmetric hand use. By calibrating the BoHA logit measures into the same frame of reference through linking, the overall measure of bimanual performance is comparable between children with asymmetric or symmetric hand use, still allowing use of separate item difficulty hierarchies.

**Conclusions:** The Both Hands Assessment (BoHA), showed strong evidence of internal construct validity for measuring effectiveness of bimanual performance and the extent of asymmetric hand use in children with bilateral cerebral palsy, MACS levels I-III.

**Keywords:** Bilateral cerebral palsy, assessment, bimanual performance, Both Hands Assessment

Most activities performed in daily life require the cooperative use of both hands. An important aspect of skilled hand use is therefore the ability to perform different types of collaborative actions with the hands ([Eliasson, 2005](#_ENREF_3)). For children with bilateral cerebral palsy (CP) the ability to use the hands together is complicated by varying degrees of motor impairments (i.e. spasticity, dyskinesia or ataxia) in both sides of the body ([Arner et al., 2008](#_ENREF_1)). In addition, accompanying disturbances of sensation, perception, cognition and behavior may further complicate the functional use of the hands and may severely influence their ability to successfully perform everyday activities ([Eliasson, 2005](#_ENREF_3); [Öhrvall et al., 2010](#_ENREF_28)).

 A population-based study by Arner et al. ([2008](#_ENREF_1)) found that nearly 70% of children with bilateral CP could handle objects, although with varying difficulty and were therefore classified at Manual Ability Classification System (MACS) levels I-III. Just over 30% were found to have very limited or no ability to handle objects and were classified at MACS levels IV and V. Moreover, when classifying each hand separately some children with bilateral CP demonstrated clearly better ability in one hand compared to the other, while others had similar abilities in both hands. Asymmetric or symmetric hand use is likely to affect the performance of bimanual tasks in different ways. For example, hand role differentiation may be less clear or more accentuated depending on degree of asymmetry of hand use, which in turn may require different treatment strategies for improving bimanual performance. However, little is known regarding how children with bilateral CP actually use both hands together and there is a scarcity of evidence-based interventions.

 One reason for this knowledge gap may be the lack of outcome measures of bimanual hand function for children with bilateral CP ([Elvrum et al., 2016](#_ENREF_4)). In contrast, for children with unilateral CP there are a few outcome measures of bimanual performance ([Holmefur & Krumlinde-Sundholm, 2016](#_ENREF_11); [Houwink et al., 2013](#_ENREF_13); [Krumlinde-Sundholm et al., 2007](#_ENREF_15); [Rosa-Rizzotto et al., 2014](#_ENREF_22)). Among these, the Assisting Hand Assessment (AHA) was developed using the Rasch measurement model analysis, which is a recommended method for construction of outcome measures in rehabilitation ([Grimby et al., 2012](#_ENREF_8); [Holmefur & Krumlinde-Sundholm, 2016](#_ENREF_11); [Krumlinde-Sundholm & Eliasson, 2003](#_ENREF_14); [Krumlinde-Sundholm et al., 2007](#_ENREF_15)). The toys in the AHA test-kit were selected to elicit bimanual handling. The toys are provided in a semi-structured play session which is video-taped, allowing observation and scoring of how effectively the child spontaneously uses both hands for activity performance ([Holmefur & Krumlinde-Sundholm, 2016](#_ENREF_11); [Krumlinde-Sundholm & Eliasson, 2003](#_ENREF_14); [Krumlinde-Sundholm et al., 2007](#_ENREF_15)). In AHA version 5, 20 items such as ability to grasp, stabilize objects and manipulate are scored from the video-recordings on a 4-point rating scale with specific criteria for each item corresponding to the following general meanings: the following general meanings: 1= does not do, 2=ineffective, 3= somewhat effective, and 4=effective ([Holmefur & Krumlinde-Sundholm, 2016](#_ENREF_11)). The AHA is widely used and has evidence of reliability and validity ([Gilmore et al., 2010](#_ENREF_6); [Holmefur et al., 2009](#_ENREF_10); [Holmefur & Krumlinde-Sundholm, 2016](#_ENREF_11); [Holmefur et al., 2007](#_ENREF_12); [Krumlinde-Sundholm et al., 2007](#_ENREF_15)). In addition, the AHA is responsive to change, allowing monitoring of development and evaluation of interventions targeting hand function in children with unilateral CP ([Green et al., 2013](#_ENREF_7); [Hoare et al., 2013](#_ENREF_9); [Nordstrand et al., 2016](#_ENREF_20); [Sakzewski et al., 2011](#_ENREF_23); [Wallen, 2016](#_ENREF_26)).

 Taking these documented advantages of the AHA into consideration, we wanted to explore if the AHA could be modified for use with children with bilateral CP. We hypothesized that bimanual performance could be observed in children with bilateral CP using the AHA test-kit, but that adaptations of the AHA test-items would be required to enable scoring of bimanual performance and quantification of degree of asymmetry in hand use.

 The aim of this study was to develop an evaluative measure of bimanual performance for children with bilateral CP, the Both Hands Assessment (BoHA), for measuring bimanual hand use, as well as quantifying a possible asymmetry between hands.

**METHODS**

The development of the BoHA involved two main steps: (1) Generation of BoHA test-items, and (2) evaluation of internal scale validity and aspects of reliability of the BoHA using Rasch measurement model analyses.

#### Participants

A convenient sample of 171 children (96 males) with bilateral CP aged 22 months to 13 years of age (mean age: 6.5 years, SD 3.2) was recruited through paediatric habilitation units in Sweden (n=91) and Norway (n=80), see Table 1. One child was 13 years old, which is above the eligible age range. However, this child functioned at a lower cognitive level compared to peers and enjoyed the test session. The children were classified at MACS levels I (n=53), II (n=56) and III (n=55). Children with bilateral CP were eligible to participate in this study if aged 18 months to 12 years of age and their manual ability was classified at MACS levels I-III, since these children can be expected to be able to handle the toys used in the BoHA test situation. Children classified at MACS levels IV-V were excluded, since they by definition have very limited, or no ability to handle objects. Hand dominance was established and defined as the hand used for writing, drawing or eating. If the child did not have clear hand dominance, the dominance was characterized as “mixed”. Informed consent was obtained from all parents and ethical approval for this study was granted by the Ethics Research Committee of Karolinska Hospital in Stockholm (ref. 2006/343-32) and by the Regional Ethical Committee for Medical Research in Mid-Norway (ref. 2012/152).

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| **Table 1**: Demographic characteristics of the included participants (n=171) with bilateral cerebral palsy  |  |
|  | Totaln (%) | Symmetryn (%) | Asymmetryn (%) |  |
| BoHA assessments  | 171 (100) | 116 (68) | 55 (32) |  |
| Age |  |  |  |  |
|  | 22-60 months | 66 (39) | 37 (32) | 29 (53) |  |
|  | 61 months – 13 years | 105 (61) | 79 (68) | 26 (47) |  |
| Gender |  |  |  |  |
|  | Males | 96 (56) | 65 (56) | 31 (56) |  |
|  | Females | 75 (44) | 51 (44) | 24 (44) |  |
| Hand dominance |  |  |  |  |
|  | Right hand | 109 (64) | 79 (68) | 30 (55) |  |
|  | Left hand | 43 (25) | 18 (16) | 25 (45) |  |
|  | Mixed | 19 (11) | 19 (16) | 0 |  |
| MACS\* |  |  |  |  |
|  | I | 53 (32) | 48 (43) |  5 (10) |  |
|  | II | 56 (34) | 38 (34) | 18 (34) |  |
|  | III | 55 (34) | 26 (23) | 29 (56) |  |

BoHA= Both Hands Assessment; Symmetry= ≤ 20% difference between

hands in BoHA unimanual sum scores; Asymmetry= ≥ 20% difference between

hands in BoHA unimanual sum scores; n=number; Hand dominance= the hand

used for writing/drawing/eating; MACS=Manual Ability Classification System; \*=7 missing MACS classifications

***Procedure***

The content of the BoHA test-items was generated from observations of bimanual play in children with bilateral CP using the toys in the AHA test-kit to elicit spontaneous collaborative use of the hands ([Krumlinde-Sundholm & Eliasson, 2003](#_ENREF_14)). For children aged 18 months to 5 years, the Small Kids AHA test-kit was applied using explorative play, while for 6 to 12 year old children the School Kids AHA test-kit was used with board games as the age-appropriate test session ([Holmefur et al., 2009](#_ENREF_10); [Krumlinde-Sundholm et al., 2007](#_ENREF_15)). Furthermore, the AHA set-up for administration and video-recording was followed except for one adjustment: In the BoHA test situation, the toys were placed on both sides of the child equally often, as opposed to the AHA test situation in which most of the objects are placed at the child’s affected hand side. The BoHA test sessions were administered and video-recorded by certified AHA-raters. All children were able to complete the play session by handling all or almost all play objects in the AHA test-kit, permitting observation and scoring of bimanual performance. The play sessions took between 15-25 minutes to complete.

#### Step 1: Item generation

The test developers (AKE, BMZ, LKS) carefully scrutinized the suitability of the original 20 AHA (version 5.0) test-items and the 4-point rating scale ([Holmefur & Krumlinde-Sundholm, 2016](#_ENREF_11)). To decide which items to include for further evaluation of the BoHA scale, the items were sorted as follows: (1) “Suitable - no changes required” when the conceptual meaning of the items and the described actions were found to be relevant and could be scored in children with bilateral CP, (2) “suitable after adaptation” when the conceptual meaning of the item was found to be relevant, but the item and the categories needed some adjustment to reflect the actions observed in children with bilateral CP, or (3) “not suitable” when the scoring categories did not fit observed performance of children with bilateral CP. In addition, it was considered whether the original AHA items were useful to be scored for each hand separately (unimanual items) or with one common score for both hands (bimanual items). The items were evaluated independently by the test developers and discrepancies were discussed until consensus was reached, based on collective observation and analyses of the children’s video-recorded performances.

 Furthermore, new test-items were generated based on object-related hand and arm actions observed in the BoHA video-recordings, but not covered by the original AHA test-items. The items and the wording of the criteria defining the 4-point rating scale for each item were developed through an iterative process among the test developers based on observation of the children’s videotaped performances. Similar to the AHA, the defined criteria for each item corresponded to the general meaning1=does not do, 2=ineffective, 3= somewhat effective, and to 4=effective

 The video-recordings of the BoHA play session were scored according to the revised and new test-items. Following this, the clinical relevance and perceived importance of each item for evaluation of bimanual performance in children with bilateral CP was appraised by the test developers who independently rated each item to be: (1) Essential, (2) probably essential, or (3) nonessential. Test-items considered to be nonessential by all test developers, were excluded prior to Rasch analyses.

#### Step 2: Evaluation of measurement properties

The Rasch measurement model for polytomous data was used to evaluate internal scale validity, including (1) *rating scale functioning*, (2) *unidimensionality,* (3) *targeting of item difficulty to person ability*, and (4) aspects of *item and person reliability* of the BoHA scale. The basic theoretical assertions of the Rasch model are that persons with greater ability are more likely to accomplish difficult test items than those with less ability, and that all persons have a greater probability of accomplishing easier test items than ones that are more difficult. Based on transformation of ordinal raw scores into interval logit measures (log-odds probability units), the Rasch model orders item calibrations hierarchically from easiest to hardest, as well as person measures from high to low ability. The logit measures range from negative to positive values, but can be rescaled to a more user-friendly 0 to 100 measure range ([Linacre, 2016b](#_ENREF_19)). The Rasch analyses were performed using the WINSTEPS computer program version 3.92.0 ([Linacre, 2016a](#_ENREF_18)). First, *rating scale functioning* was examined to determine which derivation of the Rasch polytomous model to use for further analysis ([Linacre, 2002](#_ENREF_17)).

 Second, *unidimensionality* was investigated by item and person goodness-of-fit statistics and principal components analysis of the standardized residuals. Since misfitting infit statistics represent a larger threat to test validity than outfit, criteria for acceptable infit mean square (MnSq) values were set to infit MnSq <1.4 in combination with a standardized Z-value (Zstd) <2 for the items ([Bond & Fox, 2007](#_ENREF_2); [Linacre, 2016b](#_ENREF_19)). These criteria identify items showing underfit to the Rasch model. Items showing misfit were removed from the subsequent analyses one by one, starting with the item with the highest MnSq and Zstd values until no more than 5% of items misfit the Rasch model ([Bond & Fox, 2007](#_ENREF_2)). The criteria for unidimensionality of the items were that at least 60% of the variance seen in the principal component analysis (PCA) should be explained by the measure (the BoHA scale), and less than 5% by any additional components ([Smith, 2002](#_ENREF_24)). The PCA of persons was used to investigate if there were contrasting groups of persons in the dataset ([Tennant & Conaghan, 2007](#_ENREF_25)). In addition testing for differential item functioning (DIF) was used to investigate whether the scale worked in the same way for groups with different characteristics. The DIF contrast should be at least 0.5 logits with a statistical probability of *p*<0.05 to be noticeable ([Linacre, 2016b](#_ENREF_19)).

 Third, the *targeting of item difficulty to person ability* was investigated by visual inspection of a person-item map, comparison of the means of item and person measures, as well as ceiling and floor effects ([Tennant & Conaghan, 2007](#_ENREF_25)).

 Fourth, *item and person reliability* coefficients, as well as the person separation ratios were investigated. The item reliability coefficient indicates the degree of replication of the item hierarchy with a different set of persons. The person reliability coefficient reflects the ability of the scale to reliably rank person’s relative measure location, similar to the Cronbach’s alpha. Acceptable reliability is indicated by item and person reliability coefficients ≥0.80 ([Fisher Jr, 2007](#_ENREF_5)). The person separation ratio (G) was used to calculate the number of strata (ability levels) that the scale can differentiate between using the formula: (4G+1)/3 ([Wright B, 1982](#_ENREF_27)). A scale requires at least two distinct strata to be useful for differentiating between high and low ability ([Linacre, 2016b](#_ENREF_19)).

 In addition to the Rasch analyses, the association between BoHA measures and MACS levels and age were calculated by Spearman’s rho and Pearson’s correlations using the IBM SPSS statistics 20. A high correlation with MACS would imply that BoHA can separate between different manual ability levels in a similar manner. Furthermore, a low correlation with age would suggest that BoHA measures are not related to age but ability, and BoHA can be used and results compared across different ages.

**RESULTS**

#### Item generation

Analyses of the content of the 20 AHA test-items revealed that five items were suitable with no changes required and nine were suitable after adaptation of the scoring criteria. One item, *Moves upper arm*, was regarded as not suitable since this item first and foremost measures frequency and range of movements, which was seldom the problem for children with bilateral CP (Table 2). In addition, the observations of hand use in the video-recordings resulted in the generation of three potentially new BoHA-items. These items were named *Quality of arm movements, Speed of movements* and *Postural control* in sitting. Next, the appraisal of clinical relevance resulted in the exclusion of three AHA-items (*Amount of use*, *Holds* and *Chooses assessed hand when closer to objects*) which showed a ceiling effect, while the original AHA-items *Stabilizes by weight or support* and *Stabilizes by grasp* were merged into the modified item *Stabilizes objects*.

 Thus, the item generation process resulted in 18 items for the BoHA trial version: 12 unimanual and 6 bimanual items. The 12 unimanual items were scored separately for the dominant (D) and the non-dominant (ND) hand. The unimanual sum-scores were used to calculate an asymmetry index between the two hands [(1 – (ND sum score/D sum score)) \* 100]; the higher the percentage, the greater the difference between sides. For each of the 6 bimanual items, one common score was given for both hands. This score was added to the unimanual scores, resulting in the “Both hands sum-score”, reflecting overall bimanual performance.

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| **Table 2:** Item generation for the Both Hands Assessment (BoHA) based on evaluation of the suitability of the original Assisting Hand Assessment (AHA) test-items, as well as generation of potential new test-items, and appraisal of clinical relevance. Unimanual and bimanual items are noted, as well as which items were included in the Rasch analysis. |
| ***Suitable AHA items*** | ***Unimanual***  | ***Bimanual*** | ***Rasch analyses*** |
|  |  | Moves forearm | X |  | X  |
|  |  | Varies type of grasp | X |  | X |
|  |  | Grip force regulation | X |  | X |
|  |  | Readjusts grasp |  | X | X |
|  |  | Orients objects |  | X | X |
| ***Suitable AHA-items after adaptation*** |
|  |  | Initiates use | X |  | X |
|  |  | Reaches | X |  | X |
|  |  | Grasps | X |  | X |
|  |  | Releases | X |  | X |
|  |  | Moves fingers | X |  | X |
|  |  | Manipulates | X |  | X |
|  |  | Stabilizes objects  | X |  | X |
|  |  |  | Merged from Stabilizes by grasp & Stabilizes by weight or support |  |  |  |
|  |  | Coordinates |  | X | X |
|  |  | Proceeds |  | X | X |
|  |  | Flow in bimanual tasks |  | X | X |
| ***Not suitable AHA-items*** |
|  |  | Moves upper arm | X |  |  |
| ***Potentially new items*** |
|  |  | Postural control |  | X | X |
|  |  | Quality of arm movements | X |  | X |
|  |  | Speed of movements | X |  | X |
| ***Items of less clinical relevance*** |
|  |  | Amount of use | X |  |  |
|  |  | Holds | X |  |  |
|  |  | Chooses assessed hand when closer to objects | X |  |  |

#### Measurement properties of the BoHA

For the Rasch analyses, in total 30 items were included for each of the 171 participants with no missing values, i.e. scorings of 18 items of which 12 were unimanual and scored for each hand separately and 6 were bimanual (12D + 12DH + 6 bimanual). Initial Rasch analysis of rating scale effectiveness indicated that the BoHA trial version fulfilled the criteria for rating scale functioning using the rating scale model, i.e. the average category measures and the step calibration measures advanced with the scoring category, and the 4-point rating scale had at least ten observations for each category when all items were considered ([Linacre, 2002](#_ENREF_17)). Therefore, the rating scale model was used in the further Rasch analysis.

 Goodness-of-fit statistics and the PCA items did not support unidimensionality for the 30 items and 171 children. The PCA of persons indicated two contrasting groups in the dataset. When scrutinizing the two groups we found that the amount of asymmetry between the hands was the dividing trait: In the first contrasting group 54 out of 58 children (93%) had asymmetric hand use with 20% or more difference between the hands scored on the unimanual items. In the second contrasting group, 112 out of 113 children (99%) had a more symmetric hand use with a difference between the hands of less than 20%. We therefore chose to perform separate Rasch analyses for children sorted for having an asymmetric hand use, i.e. ≥20% difference between hands (n=55) or a symmetric hand use i.e. <20% difference between the hands (n=116). The rationale for dividing the children into two groups based on degree of difference between the hands was confirmed by the DIF analysis indicating that 87% of the items functioned differently for children with asymmetric and symmetric hand use.

 The average category measures and the step calibration measures were found to increase with the scoring category for the BoHA measures in both groups of children. None of the children achieved a minimum score, whereas two (1.7%) children with symmetric hand use received a maximum score. These two children were removed from subsequent analyses.

 Goodness-of-fit statistics showed that the items *Postural control* and *Moves forearm* displayed infit misfit both for children with symmetric and asymmetric hand use. Their removal resulted in 95% of items having acceptable item infit, with only *Reaches* showing infit misfit for the dominant hand for children with symmetric hand use and for the non-dominant hand for children with asymmetric hand use. Standard errors (SE) of the resulting 27 evaluated items (Tables 3 and 4), i.e. for 16 items of which 11 were unimanual and scored for each hand separately and 5 were bimanual (11D + 11DH + 5 bimanual), indicated good precision of the estimates. Furthermore, the PCA for the items indicated unidimensional scales with acceptable variance explained by the measure both for children with symmetric (69.1%) and asymmetric (73.8%) hand use. The unexplained variance in the second largest dimension was acceptable for children with symmetric hand use (4.5%) while it was somewhat high (6.5%) for children with asymmetric hand use. Although the latter improved to 4.4% when the four children with misfitting person measures were excluded, we decided from a clinical perspective to accept the slightly too high unexplained variance. The resulting goodness-of-fit statistics for the person ability measures indicated that 96% of the children with symmetric hand use and 93% of the children with asymmetric hand use demonstrated an acceptable fit to the Rasch model.

Insert Tables 3 & 4

 The most difficult item for all children was *Manipulates* with the non-dominant hand, while the easiest item was *Initiates* *use* with the dominant hand, shown in the item hierarchies listed in Tables III and IV. Furthermore, the person separation ratios and the person reliability coefficients for children with symmetric (4.36 and 0.95) and asymmetric (5.19 and 0.96) hand use indicated that the bimanual performance could be separated into 6 and 7 different ability levels, respectively.

 To make it possible to report and compare the bimanual performance outcomes for all children on the same measure scale, the two scales were linked using anchoring methods ([Linacre, 2016b](#_ENREF_19)). The item difficulty measures and item calibration structure for three items not displaying DIF (*Proceeds, ND Stabilizes objects, ND Speed of movements*) were anchored. Anchoring of items “locks” the difficulty measures of these items, while the other

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| **Table 3:** Item difficulty order, item calibrations and item fit statistics for children with symmetric hand use. The 11 unimanual items were scored separately for the dominant (D) and the non-dominant (ND) hand and the 5 bimanual (B) items were scored with one common score for both hands. |
| Item | Measure | Infit | Outfit | PMC |
| Logits | SE | MnSq | Zstd | Mnsq | Zstd |
| ND Manipulates |  4.20 | 0.22 | 1.29 |  1.9 | 1.46 |  2.1 | 0.62 |
| ND Grip force regulation |  2.54 | 0.21 | 0.74 | -2.0 | 0.65 | -2.1 | 0.83 |
| D Manipulates |  2.27 | 0.21 | 1.15 |  1.1 | 1.07 |  0.4 | 0.73 |
| D Grip force regulation |  1.96 | 0.21 | 1.02 |  0.2 | 0.93 | -0.4 | 0.77 |
| B Proceeds |  1.65 | 0.21 | 1.30 |  2.1 | 1.40 |  2.1 | 0.79 |
| B Flow in bimanual performance |  1.47 | 0.21 | 0.84 | -1.2 | 0.84 | -0.9 | 0.89 |
| B Coordinates |  1.29 | 0.21 | 0.85 | -1.1 | 0.86 | -0.8 | 0.86 |
| ND Stabilizes objects |  0.90 | 0.21 | 1.04 |  0.4 | 1.00 |  0.1 | 0.78 |
| ND Moves fingers |  0.81 | 0.21 | 0.80 | -1.6 | 0.79 | -1.1 | 0.82 |
| ND Varies type of grasp |  0.59 | 0.21 | 0.78 | -1.7 | 0.76 | -1.2 | 0.84 |
| B Readjusts grasp |  0.55 | 0.21 | 0.75 | -2.1 | 0.65 | -2.0 | 0.86 |
| D Moves fingers |  0.37 | 0.21 | 0.74 | -2.2 | 0.78 | -1.0 | 0.83 |
| B Orients objects |  0.10 | 0.21 | 0.95 | -0.3 | 0.89 | -0.4 | 0.76 |
| ND Quality of arm movements | -0.04 | 0.21 | 1.12 |  0.9 | 1.05 |  0.3 | 0.78 |
| ND Grasps | -0.08 | 0.21 | 0.79 | -1.6 | 0.65 | -1.5 | 0.85 |
| D Stabilizes objects | -0.13 | 0.21 | 1.26 |  1.9 | 1.22 |  0.9 | 0.73 |
| D Varies type of grasp | -0.27 | 0.22 | 1.1 |  0.8 | 1.05 |  0.3 | 0.76 |
| D Quality of arm movements | -0.40 | 0.22 | 1.12 |  0.9 | 1.03 |  0.2 | 0.76 |
| ND Speed of movements | -0.50 | 0.22 | 1.08 |  0.7 | 0.98 |  0.0 | 0.77 |
| D Speed of movements | -0.59 | 0.22 | 1.07 |  0.5 | 0.97 |  0.0 | 0.76 |
| ND Releases | -1.34 | 0.23 | 0.69 | -2.4 | 0.58 | -1.1 | 0.81 |
| D Grasps | -1.44 | 0.23 | 0.81 | -1.4 | 0.64 | -0.9 | 0.79 |
| ND Reaches | -1.71 | 0.24 | 1.33 |  2.0 | 1.15 |  0.5 | 0.68 |
| D Releases | -2.06 | 0.24 | 0.49 | -4.1 | 0.41 | -1.6 | 0.81 |
| ND Initiates | -2.48 | 0.25 | 1.35 |  2.0 | 1.43 |  0.9 | 0.61 |
| **D Reaches** | -3.09 | 0.27 | **1.46** |  **2.4** | 1.19 |  0.5 | 0.60 |
| D Initiates | -4.56 | 0.33 | 1.37 |  1.7 | 0.66 | -0.3 | 0.52 |
| Mean | 0.00 | 0.22 | 1.01 | -0.1 | 0.93 | -0.3 |  |
| Standard deviation (SD) | 1.83 | 0.02 | 0.25 |  1.7 | 0.26 |  1.1 |  |

SE=standard error; MnSq=Mean Square; Zstd=Z score; PMC=point measure correlation

unanchored items are free to be ranked, creating new hierarchies through new Rasch analysis. The displacements between the anchored and unanchored logit measures were all <±0.18 logits and considerably smaller than the SE for every item, indicating no statistical difference between the measures (Supplemental Tables 1 and 2) ([O'Neill, 2013](#_ENREF_21)). To make the logit measures more user-friendly they were converted to a 0-100 scale logit based BoHA-units ([Linacre, 2016b](#_ENREF_19)).

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| **Table 4**: Item difficulty order, item calibrations and item fit statistics for children with asymmetric hand use. The 11 unimanual items were scored separately for the dominant (D) and the non-dominant (ND) hand and the 5 bimanual (B) items were scored with one common score for both hands. |
| Item | Measure | Infit | Outfit | PMC |
| Logits | SE | MnSq | Zstd | Mnsq | Zstd |  |
| ND Manipulates |  4.32 | 0.31 | 0.93 | -0.3 | 0.84 | -0.6 | 0.59 |
| ND Varies type of grasp |  3.86 | 0.30 | 0.90 | -0.5 | 0.86 | -0.6 | 0.71 |
| B Flow in bimanual performance |  3.23 | 0.30 | 0.73 | -1.5 | 0.64 | -1.8 | 0.87 |
| ND Grip force regulation |  3.06 | 0.30 | 0.98 |  0.0 | 0.97 | -0.1 | 0.66 |
| B Readjusts grasp |  2.88 | 0.29 | 1.01 |  0.1 | 1.03 |  0.2 | 0.72 |
| **ND Reaches** |  2.71 | 0.29 | **1.54** |  **2.5** | 1.63 |  2.5 | 0.53 |
| ND Grasps |  2.54 | 0.29 | 1.06 |  0.4 | 1.03 |  0.2 | 0.48 |
| B Coordinates |  1.94 | 0.29 | 0.95 | -0.2 | 0.91 | -0.4 | 0.85 |
| ND Moves fingers |  1.77 | 0.29 | 0.60 | -2.3 | 0.56 | -2.4 | 0.62 |
| ND Releases |  1.61 | 0.29 | 0.82 | -0.9 | 0.81 | -0.9 | 0.69 |
| B Proceeds |  1.52 | 0.29 | 1.20 |  1.0 | 1.19 |  0.9 | 0.86 |
| ND Quality of arm movements |  1.52 | 0.29 | 0.51 | -2.9 | 0.44 | -3.2 | 0.73 |
| ND Stabilizes objects |  1.36 | 0.29 | 0.82 | -0.9 | 0.77 | -1.1 | 0.71 |
| B Orients objects |  1.11 | 0.29 | 1.24 |  1.2 | 1.30 |  1.4 | 0.75 |
| ND Initiates |  0.95 | 0.29 | 0.76 | -1.3 | 0.81 | -0.8 | 0.69 |
| ND Speed of movements |  0.07 | 0.28 | 0.87 | -0.6 | 0.85 | -0.7 | 0.85 |
| D Manipulates | -0.84 | 0.27 | 1.19 |  1.0 | 1.15 |  0.8 | 0.73 |
| D Grip force regulation | -1.44 | 0.27 | 1.18 |  1.0 | 1.21 |  1.0 | 0.59 |
| D Varies type of grasp | -2.10 | 0.27 | 1.05 |  0.3 | 1.03 |  0.2 | 0.72 |
| D Moves fingers | -2.40 | 0.27 | 0.99 |  0.0 | 0.96 | -0.1 | 0.63 |
| D Speed of movements | -2.93 | 0.28 | 0.97 | -0.1 | 0.94 | -0.1 | 0.62 |
| D Stabilizes objects | -3.01 | 0.28 | 1.32 |  1.7 | 1.32 |  1.1 | 0.63 |
| D Grasps | -3.48 | 0.29 | 0.91 | -0.4 | 1.02 |  0.2 | 0.70 |
| D Quality of arm movements | -3.57 | 0.29 | 1.17 |  0.9 | 1.14 |  0.5 | 0.62 |
| D Releases | -4.26 | 0.30 | 0.77 | -1.2 | 0.72 | -0.5 | 0.63 |
| D Reaches | -4.64 | 0.32 | 1.35 |  1.6 | 1.11 |  0.4 | 0.53 |
| D Initiates use | -5.78 | 0.37 | 1.05 |  0.3 | 0.82 |  0.0 | 0.47 |
| Mean | 0.00 | 0.29 | 1.00 |  0.0 | 0.97 | -0.1 |  |
| Standard deviation (SD) | 2.87 | 0.02 | 0.23 |  1.2 | 0.25 |  1.1 |  |

SE=standard error; MnSq=Mean Square; Zstd=Z score; PMC=point measure correlation

 The targeting of the item difficulty measures to the person ability measures expressed in BoHA-units (Figure) were well matched and close to the average difficulty of test-items (mean: 50) for children with asymmetric hand use (mean BoHA-units: 52, range: 31-76). For children with symmetric hand use, the mean BoHA-unit (mean: 67, range: 41-100) was higher than the average difficulty of test-items.

 ***Children with symmetric hand use Children with asymmetric hand useA***

 ***Person****| ITEM SCORES BoHA-units ITEM SCORES |****Person***

 *| 1-2 | 2-3 | 3-4 1-2 | 2-3 | 3-4 |*

 *XX | | |* ***100*** *| | |*

 *| | | | | |*

 *| | | | | |*

 *| | | | | |*

 *| | | | | |*

 *XXXX | | | | | |*

 *| | | | | |*

 *| | |* ***90*** *| | X |*

 *X | | | | | |*

 *| | | X | | X |*

 *X | | | | | |*

 *| | | | | X |*

 *XXXXX | | | | | XX |*

 *XX | | | X | | XX |*

 *XXXXXXX | | | X* ***80*** *| | |*

 *X | | | X | | XX |*

 *XXXX | | | XX | | XXX |*

 *XX | | | XX | | XX | X*

 *X | | | X | | X |*

*XXXXXXXXXX | | | XXX | | | X*

 *XXX | | | X | | | X*

 *XXXXXXXX | | | XXXXX* ***70*** *| X | X |*

 *| | X | XX | X | |*

 *XXXXXXX | | | | | X | X*

 *XXXX | | | | X | | X*

 *XXXXXXX | | | XX | XX | X | X*

 *XX | | X | X | XX | | XX*

 *XXX | | X | X | | | XXX*

 *XXXXXX | | X | X* ***60*** *| XX | X |*

 *XXXXXX | | XX | | XXX | X | X*

 *XXXX | | XX | X | XX | X | XXX*

 *XXXXX | | X | | X | X | XXXXX*

 *| | XXX | | | X | XXXX*

 *| | X | | | X | XXX*

 *XXXXXX | | X | | | | XX*

 *XXXX | | XXXX | X* ***50*** *X | X | X | XXXX*

 *XX | | XX | | | | XX*

 *XXX | X | | X | X | | XX*

 *XX | | | | | X | XXX*

 *X | | XX | X | X | | XXXXXX*

 *X | | X | XX | | |*

 *X | X | X | XX | | X | X*

 *X | X | X |* ***40*** *| X | | XXX*

 *| X | | XX | X | | XX*

 *| XX | X | XXX | X | | XX*

 *| XX | | XX | X | |*

 *| X | | X | XX | |*

 *| XXX | | | | |*

 *| X | X | | | |*

 *| XXXXX | |* ***30*** *| X | | X*

 *| XX | | X | | |*

 *| | | | X | |*

 *| | | X | | |*

 *| XX | | | | |*

 *| X | | X | X | |*

 *| X | | | | |*

 *| X | |* ***20*** *X | | |*

 *| | | | | |*

 *| X | | X | | |*

 *| | | X | | |*

 *| | | X | | |*

 *| | | XX | | |*

 *| X | | | | |*

 *| | |* ***10*** *X | | |*

 *| | | | | |*

 *| | | X | | |*

 *| | | | | |*

 *| | | X | | |*

 *| | |* ***0*** *| | |*

 ***Less able*** *| | |* ***Easier item*** *| | |* ***Less able***

**Figure 1:** Variable map illustrating the targeting of item difficulty to person ability for children with bilateral cerebral palsy assessed with the Both Hands Assessment (BoHA). The targeting for children with more symmetrical hand use (<20 difference between hands) is illustrated on the left side of the figure, while the targeting of children with asymmetrical hand use (≥20% difference between hands) is illustrated on the right side of the figure. The more able persons and more difficult items are at the top of the map, and lower performing persons and easier items are at the bottom. X represents one person or one item. The item measures are shown on their threshold values between a score of 1 or 2, 2 or 3, and 3 or 4, respectively. Measures are given in BoHA units.

 There was a strong correlation between the BoHA-units and the MACS (Spearman’s rho: 0.74, p≤0.001). In contrast, there was no correlation between the BoHA-units and age (Pearson’s r=0.17, p=0.03) or gender (Point biserial correlation=0.04, p=0.6).

**DISCUSSION**

The results from this study provide evidence of good internal scale validity and item and person reliability for the BoHA as a measure of bimanual performance in children with bilateral CP, 18 months to 12 years, with manual ability classified at MACS levels I-III. One of the strengths of the BoHA is the ability to measure and compare effectiveness of bimanual performance regardless of degree of asymmetric or symmetric hand use in children with bilateral CP, while still allowing use of separate item difficulty hierarchies. The logical ordering of the item difficulty hierarchies for children with asymmetric or symmetric hand use corresponded well with what we would expect from clinical experience. For example, for children with asymmetric hand use, all items for the non-dominant hand were more difficult than the items for the dominant hand. In contrast, for children with symmetric hand use, the overall pattern indicated that unimanual items that were difficult for the non-dominant hand (i.e. *Manipulates* and *Grip force regulation*) were also rather difficult for the dominant hand, while easy items for the dominant hand (i.e. *Initiate use*) were similarly rather easy for the non-dominant hand.

 The item difficulty hierarchies are used to identify items the child performs well, as well as items that are still not accomplished, but are close to the child’s next ability level. Items close to the child’s next ability level may represent the “just right challenge” for the individual child, by indicating possible goal areas for interventions. The lack of correlation between the BoHA measures and the age of the children (r=0.17) indicates that the item difficulty hierarchies reflect steps of increasing ability rather than age-dependent development. In addition, the ability of the BoHA to separate bimanual performance into 6 and 7 different ability levels, indicate that BoHA is likely to be responsive to change. Thus, the BoHA seems like a promising measure for planning interventions and measuring change over time or in response to intervention. However, further research is needed to investigate test-retest and rater reliability, as well as confirming responsiveness of the BoHA as an outcome measure.

 Observed differences in bimanual performance between children with bilateral and unilateral CP confirmed the slightly divergent theoretical construct underlying the BoHA (effective use of both hands in bimanual tasks) and the AHA (effective use of the assisting hand in bimanual tasks), and confirmed the need for separate measures. For example, hand role differentiation was less obvious in children with bilateral CP. The majority of the children used both hands frequently and the hand closest to the objects was most commonly used, whether it was the dominant or the non-dominant hand. However, frequent use of both hands did not necessarily indicate good coordination. Actually, the item *Coordinates* was one of the more difficult items, especially among children with symmetric hand use. In contrast, the ability to coordinate was one of the easier items for children with unilateral CP ([Holmefur & Krumlinde-Sundholm, 2016](#_ENREF_11)). In some children with bilateral CP, decreased coordination may be related to slowness of movements, making bimanual performance somewhat ineffective. Furthermore, imprecise or exaggerated movements were commonly observed, while decreased range of motion, which is common in children with unilateral CP, was less frequently observed.

#### Limitations

The sample size requirement for performing Rasch analysis is approximately 150 ([Linacre, 1994](#_ENREF_16)). Our sample consisted of 171 participants, but the Rasch analyses indicated that it was necessary to split the population in two groups resulting in smaller sample sizes for both groups, in particular for the group of children with asymmetric hand use (n=55). This may have produced less precise estimates and thus is a limitation. However, the SE for both analyses were generally small, indicating that the number of observations used to make the estimate was sufficient ([Linacre, 2016b](#_ENREF_19)). Still, further analyses including a larger number of children are desired to confirm our results. In addition, further studies are required to investigate potential differences in bimanual performance for children with spastic, dyskinetic or ataxic subtypes. We included children with all subtypes in our study, but the information regarding subtype was incomplete and there were not enough children in each subtype to draw any conclusions.

***Application to Practice***

We recommend use of the BoHA for measuring bimanual performance in children with bilateral CP, 18 months to 12 years, with manual ability classified at MACS levels I-III. Bimanual performance may be the most important aspect of hand use since most daily life activities demand the use of both hands together. The purpose of the BoHA is to measure and describe the child’s spontaneous way of using both hands together, when performing bimanual tasks. The BoHA is performed in two steps: First a test session including age-relevant bimanual tasks is conducted and video-recorded. The test session should take about 15-20 minutes, be playful, and standardised according to the manual concerning which objects to use and how to present them. Second, the child’s effective bimanual performance is scored from the video-recording on 16 items (11 unimanual and 5 bimanual), where each item receives a score on a 4-point rating scale.

 The eleven unimanual items are scored separately for the dominant (D) and the non-dominant (ND) hand. The unimanual sum scores are used to determine a possible difference between the hands, reported as an asymmetry index; the higher the number, the greater the difference between the sides. In addition, for the five bimanual items, one common score is given for both hands resulting in a possible raw-score range of 27-108 points. This raw-score is converted to an interval level logit based “Both hands measure” called BoHA-units on a 0-100 scale, reflecting overall bimanual performance. The BoHA-unit should be used when reporting the bimanual performance. The scoring takes approximately 45 minutes. After the scoring is completed, an outcome report sheet is produced reflecting the relation between the child’s ability measure and the item difficulty hierarchies for children with asymmetric or symmetric hand use, respectively. This information can probably be used to plan intervention by matching the individual child’s ability measure to the item difficulty calibrations to find out which item is next to target in treatment. However, this procedure needs to be further investigated and described.

**CONCLUSION**

This study reported the development and internal validation of an assessment of bimanual performance, the BoHA, for children with bilateral CP, 18 months – 12 years, MACS levels I-III. Sixteen BoHA-items exhibited strong evidence for internal scale validity and item and person reliability for children with asymmetric or symmetric hand use. Thus, the BoHA has the potential to become a useful tool for describing and evaluating bimanual performance in children with bilateral CP.

 Further studies are required to investigate responsiveness to change, rater reliability (test-retest, intra- and inter-rater), and the relationship with other outcome measures.

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