[Original article: 1 Figure, 3 Tables; 6 Videos]

Assessment of mirror movements in children and adolescents with unilateral cerebral palsy: reliability of the Woods and Teuber scale

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ABBREVIATION

ICC	Intraclass correlation coefficient
MACS	Manual Ability Classification System
AHA	Assisting Hand Assessment

[Abstract]

AIM To investigate the inter- and intrarater reliability of the Woods and Teuber scale to detect mirror movements in children and adolescents with unilateral cerebral palsy (CP).

METHOD A convenience sample of children and adolescents with unilateral CP (*n*=68; 31 males, 37 females; mean age 12y 2mo, SD 3y 6mo) in Manual Ability Classification levels I

to III was recruited from Norway, Australia, and Belgium. Three therapists scored mirror movements according to the Woods and Teuber scale from three video-recorded tasks at two separate time points. A two-way, mixed model regression was used to calculate intraclass correlation coefficients (ICCs) reflecting overall inter- and intrarater reliability. In addition, ICCs for each hand and task were calculated separately.

RESULTS The overall interrater reliability ICC was 0.90 and the corresponding intrarater reliability ICC was 0.92. The ICCs for each hand ranged from 0.86 to 0.92 and for each task from 0.63 to 0.89.

INTERPRETATION The Woods and Teuber scale shows excellent reliability for scoring mirror movements in children and adolescents with unilateral CP. The assessment is easy to administer with no need for specific equipment and scoring can be determined from short video-recordings, making it a feasible instrument in research and clinical practice.

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What this paper adds

- The Woods and Teuber scale produces reliable measures of mirror movements.
- Scorings can reliably be determined from short videos recorded from above.
- The Woods and Teuber scale has good clinical utility.

[main text]

Mirror movements are involuntary movements activated by voluntary movements of the contralateral limb.[1,2] They are more often observed in the upper limbs and intensity may increase due to growing task complexity or fatigue.[3] Mirror movements are present in typically developing children, but decrease gradually between 5 and 8 years of age and have usually disappeared by 10 years of age.[4]

In many children with unilateral cerebral palsy (CP) mirror movements are more pronounced and often persist after the age of 10 years.[1,5,6] Two underlying mechanisms are postulated for the presence and persistence of mirror movements in these children.[2,7,8] First, a reorganization in the corticospinal system of the motor cortex can result in both hands being controlled by the less-affected brain hemisphere.[2,6,8] This is thought to cause mirror movements primarily in the more-affected hand.[6,8] Second, a dysfunction of the corpus callosum may result in bilateral cortical activation due to an imbalance in interhemispheric inhibition.[7] This bilateral activation of the motor cortices may lead to motor overflow, causing mirror movements in the less-affected hand when intentionally moving the more-affected hand.[3,7,8] Studies have demonstrated that mirror movements seem to be more prominent in the less-affected hand (i.e. when moving the more-affected hand), and that mirror movements in this hand are more often related to impaired bimanual performance.[3,5,7,9–11] Results regarding the association between mirror movements in the more-affected hand and bimanual performance are less conclusive.[3,5,9,12,13] Mirror movements may assist in activities requiring symmetric hand use,

but may cause difficulties in performing activities in daily life where asymmetric hand use is required.[7] Moreover, it has been suggested that the response to different kinds of intensive therapy programmes are influenced by the degree of mirror movements in children with unilateral CP.[5,14–17] Therefore, reliable assessment of mirror movements in future studies of upper limb intervention may assist in better understanding their influence on outcomes.[5,14]

The most commonly used instrument to detect the presence of mirror movements in children with unilateral CP is the Woods and Teuber scale.[1] The Woods and Teuber scale is an observation-based assessment with five distinct levels describing the degree of mirror movements.[1] The scale was developed in 1978 and measures mirror movements observed in the resting hand, while the other hand is moved intentionally, performing three instructed tasks.[1] Originally, the Woods and Teuber scale was administered using the following tasks: (1) repetitive tapping of the index finger on the thumb, (2) alternating supination and pronation of the hand, and (3) repetitive alternate touching of each fingertip. Since then, variants of the tasks have been administered (i.e. fist opening and clenching and finger tapping on a table). More recently, laboratory-based assessments, such as the Windmill task[9] and grip force devices,[13,18] have also been used as alternative methods to measure mirror movements. These methods provide objective quantification of mirror movements but require computerized equipment that is not clinically available. The Woods and Teuber scale does not require specific equipment and remains the primary clinical method to detect mirror movements.[19] It has been used in numerous studies to investigate the relationship between mirror movements and brain damage, motor impairments, or bimanual performance in children with unilateral CP.[5,8,11,13]

While the Woods and Teuber scale has been used clinically and in research for more than four decades, information regarding the measurement properties of the scale remains largely unknown.[7] In 2016, Klingels et al.[7] reported high intra- and interrater reliability with

intraclass correlation coefficients (ICCs) of >0.82. Furthermore, Riddell et al.[10] recently reported high interrater reliability (ICC 0.87) for a modified Woods and Teuber scale. However, the main purpose of these two studies was not to investigate reliability. The reliability analysis was performed on a subsample of only 20 children and included two raters in the study by Klingels et al.,[7] while Riddell et al. included three raters with only 18 participants.[10] Moreover, scarce information was provided regarding the procedures and sample characteristics.[7,10] Further investigation of the measurement properties of the Woods and Teuber scale is, therefore, required to confirm these results.[20] The aim of this study was to investigate intra- and interrater reliability of the Woods and Teuber scale, when assessing mirror movements in a large group of children and adolescents with unilateral CP.

METHOD

This was a multicentre study with a cross-sectional design using data from prior studies, performed in Norway, Australia, and Belgium. All participants were recruited through convenience sampling. The Norwegian participants were recruited from the outpatient clinic at St. Olav's University Hospital in Trondheim between 2011 and 2015. The participants from Australia were recruited at Monash Children's Hospital in Melbourne between 2015 and 2018. The Belgian participants were recruited at the University Hospitals Leuven between 2014 and 2017. The participants were eligible to participate if they met the following criteria: (1) diagnosis of spastic unilateral CP, (2) aged 5 to 20 years at the time of recruitment, and (3) able to sufficiently cooperate to complete the assessment. Participants were excluded if they had undergone upper limb surgery within 12 months of assessment or been injected with botulinum neurotoxin A within 3 to 6 months of assessment.

Ethical approval for the study was granted at all sites by the Regional Ethics Committee in Mid-Norway (REK 2011/1451 and 2015/1744), the Human Research Ethics Committee at

Monash Children's Hospital, Victoria (HREC approval 12167B), and the Ethics Committee at the University Hospitals Leuven (S55555 and S56513). All participants provided written informed consent (including written consent from the parents of adolescents under the age of 16y) to participate in the study. All data used were deidentified using an ID code for each participant.

Data collection

Background variables such as sex, age, and side of hemiplegia were registered. In addition, the severity of hand function was described by means of the Manual Ability Classification System (MACS) levels and the Assisting Hand Assessment (AHA).[21,22]

To collect data on mirror movements, three repetitive tasks based on the Woods and Teuber assessment were performed and videotaped for later scoring. For the Norwegian and Australian participants, the following tasks were performed: (1) fist opening and clenching; (2) repetitive tapping of the index finger on the thumb; and (3) simultaneously tapping the fingers on a table. The Belgian participants performed: (1) fist opening and clenching; (2) opposition of four fingers sequentially to the thumb; and (3) sequentially tapping the fingers on a table. The assessment of mirror movements was performed with the participants seated comfortably at a table with the forearms resting on the table surface or at an elevated rim, providing space to move the hands freely. The participants were instructed to execute each repetitive task at a natural speed for 10 to 15 seconds with each hand individually, while the other hand was resting. Thereafter, the next task was performed with no break between tasks. Thus, the whole assessment lasted up to a maximum of 3 minutes. All tasks were video recorded with the video camera placed in front of or above the participant orthogonally to the table surface. The video-recordings captured the participant's forearm and hands and were used to rate mirror movements for the resting hand, according to the 5 levels of the Woods and Teuber scale (see Supporting information): (0) no clear imitative movements (Video S1);

(1) barely discernible repetitive movements (Video S2); (2) slight mirror movements (Video S3) or stronger, but briefer, repetitive movements (Video S4); (3) strong and sustained repetitive movements (Video S5); and (4) movements equal to those observed in the active hand (Video S6).[1]

Mirror movement scoring procedure

Three raters scored mirror movements according to the Woods and Teuber scale. The raters were a certified occupational therapist (rater A and B) or a physiotherapist (rater C) and participated in a training period to familiarize themselves with the Woods and Teuber scale. During the rating period the raters had access to videos exemplifying the 5 levels of the Woods and Teuber scale. In addition, they individually scored mirror movements from 10 video-recordings not included in the study, before meeting to discuss the Woods and Teuber scorings. After the training period, the raters individually scored the videos from the included participants twice, with a minimum of 2 weeks between the ratings (rating 1 and 2). For each participant, three tasks were scored for the left and right hand separately, with scores ranging from 0 to 4 for each task. To minimize the risk of recall bias, two sets of the video-recordings were created using a random order generator so that each participant received a different order number at rating 1 and 2. The key for coupling the order numbers for rating 1 and 2 to each participant's study identification number was stored locally in a safe digital location at the Norwegian University of Science and Technology in Trondheim. None of the raters accessed this location during the rating period.

Data analyses

We investigated inter- and intrarater reliability for the sum of Woods and Teuber scores for both hands for three tasks (scores ranging from 0–24), for the more-affected and less-affected hand separately (scores ranging from 0–12), and for each task for each hand separately (scores ranging from 0–4). In addition, separate analyses were performed for the variants of tasks 2

and 3. We used a two-way, mixed model regression with classification level as the dependent variable, the test replications (rating 1 and 2) as the fixed factor, and raters and participants as crossed random effects.[23] This model takes account of possible differences between raters and between ratings 1 and 2. The interrater reliability ICC was calculated as the between participants variance, divided by the total variance.[24] Furthermore, the intrarater reliability ICC was calculated as the sum of the between participants variance and between raters variance, divided by the total variance.[24]

RESULTS

A total of 68 participants with unilateral CP, in MACS levels I to III, were recruited: 19 from Norway, 23 from Australia, and 26 from Belgium (Table 1). Most participants were classified in MACS levels I (29%) and II (68%). Two participants were classified in MACS level III (3%). The mean AHA units were similar for the Norwegian and Belgium participants (mean AHA units 66 and 67), while the Australian participants scored significantly lower (mean AHA unit 52, p=0.01). The mean (SD) age for all participants was 12 years 2 months (3y 6mo); for Norwegian participants it was 15 years 11 months (2y 5mo); for Australian participants it was 10 years 5 months (2y 6mo), and for Belgian participants it was 11 years (2y 8mo). There was one missing value at rating 1 (n=67), while rating 2 was complete (n=68).

The mean overall scores (total score of three tasks) for each combination of time points (rating 1 and 2), raters, and country are shown in Figure 1.

In the mixed effect regression model, the mean overall score at rating 2 was 1.03 points (p<0.001), lower than at rating 1. The overall ICC for interrater reliability, calculated from both ratings, was 0.90, and the corresponding intrarater reliability ICC was 0.92 (Table 2).

Among the variance components used to calculate the ICCs, the variance between the participants was the largest (33.44, $p \leq 0.001$). The variance between raters was small (0.74), but statistically significant (likelihood ratio test, $p < 0.001$) with rater B showing a tendency to rate higher than rater C, who tended to rate higher than rater A (Fig. 1). Overall, the average ratings were lower for the Belgian than the Australian and Norwegian participants, but these differences were not statistically significant ($p = 0.14$).

The inter- and intrarater reliability coefficients for the more-affected and less-affected hand for the total scores for three tasks, as well as for each task separately, are shown in Table 2. All reliability indices for the less-affected hand were somewhat higher (ICC estimates between 0.84–0.92) compared to the corresponding ICCs for the more-affected hand (estimates between 0.77–0.88). The ICCs for tasks 2 and 3 performed in Belgium were lower than the ICCs for the tasks performed in Norway and Australia.

DISCUSSION

This study demonstrates that the Woods and Teuber scale has excellent reliability as an assessment of mirror movements in children and adolescents with unilateral CP. The overall interrater reliability ICC was 0.90, while the corresponding intrarater reliability ICC was 0.92. This suggests that the Woods and Teuber scale can be a useful instrument in research and clinical practice by providing reliable and easily accessible information regarding the degree of mirror movements in children and adolescents with unilateral CP. According to our results, the estimated reliability was higher for mirror movements in the less-affected hand (ICC estimates between 0.84–0.92) compared to the more affected hand (ICC estimates from 0.77–0.88). Furthermore, our results indicate that the tasks performed in Norway and Australia, in general, produced more reliable results compared to the tasks performed in Belgium that involved sequential finger movements.

The results of the present study are consistent with those from Klingels et al.[7] who reported evidence of high inter- and intrarater reliability of the Woods and Teuber scale in 20 children with unilateral CP. Overall inter- and intrarater reliability was not stated, but ICCs of ≥0.82 were reported for each task for each hand separately.[7] Similar results regarding interrater reliability have been reported for a modified Woods and Teuber scale in 18 children with unilateral CP (ICCs ranging from 0.82–0.91).[10]

The Woods and Teuber scale has good clinical utility and is quick and easy to administer. It does not require the use of any specific equipment, which is preferable in clinical practice and research.[1] Scoring the Woods and Teuber scale can be undertaken by direct observation or from short video-recordings (≤3min), as in the current study. The use of video-recordings enables the use of blinded raters, which can be advantageous, especially for research.

It is important to acknowledge that the lack of standardization of the tasks during administration may hinder comparison of results between studies, since differences in the tasks used might affect the degree of mirror movements.[1,4,19] It has been suggested that highly repetitive and simple motor tasks are more appropriate to assess the presence of mirror movements.[8] In our study, we administered tasks that differed from those used in the original study by Woods and Teuber,[1] but similar to those tasks that were used in recent research.[3,7,19] In several recent studies, the alternating supination and pronation of the hand has been substituted with fist opening and clenching, since forceful gripping movements may elicit clearer mirror movements.[19] This is supported by Klingels et al.[7] who reported a higher occurrence of mirror movements for the task requiring fist opening and clenching (task 1), compared to tasks requiring sequential finger opposition and finger tapping. Results reported by Zielinski et al.[19] also indicate higher sensitivity for this task (fist opening and clenching, task 1) compared with the tasks involving sequential finger opposition and finger tapping. These sensitivity results are consistent with our results and support continued use of task 1.

Nonetheless, the validity of the various tasks should be further investigated to help guide consistent administration of the Woods and Teuber classification in children with unilateral CP, including whether only using task 1 (fist opening and clenching) is sufficient for detection of mirror movements.

Furthermore, guidelines for training and administration may ensure more reliable results when using the Woods and Teuber scale. In the present study, the raters completed training before undertaking assessment by using video examples showing varying degrees of mirror movements and discussing the Woods and Teuber classification levels. This may have positively affected the high reliability indices. If video-recordings are used for assessment, it is also important to ensure high quality recordings. In the present study, there seems to be more consistent scorings between raters for the participants included in Norway. This could be due to the quality of the video-recordings. All videos from Norway were recorded above the participant, orthogonally to the table surface, using a standardized distance from the camera to the table surface. Furthermore, downlights (from the ceiling) were used to minimize possible shadows from the hands when recording hand movements.

While the results from this study demonstrate that the Woods and Teuber scale is a highly reliable tool for scoring mirror movements in children with unilateral CP, it remains unclear whether or not the scale is capable of detecting changes in mirror movements after intervention or during development.[14] The Woods and Teuber scale uses an ordinal scale with five relatively broad scoring levels that are determined from subjective observations of mirror movements based on their similarity with the intended movement.[1] If the movement range is restricted because of muscle overactivity, stiffness, or weakness, it may be more difficult to detect mirror movements in the more-affected hand. The somewhat higher ICCs for the less-affected hand, reported in our study and in the study by Klingels et al.,[7] provide support for this hypothesis. Laboratory based assessments use grip-force devices to measure the degree of

mirror movements, which may present more objective, less rater-dependent interval-level data. Thus, these assessments may be more sensitive in determining subtle changes after interventions.[18,19] Accordingly, the Woods and Teuber scale may be most suitable for determining the presence and degree of mirror movements, whereas the advantage of quantitative tools using interval-level data is that they are more objective, less rater-dependent, and may more easily detect intensity levels of mirror movements.[19,18]

Limitations

In this study, we included videos from studies previously undertaken across three different countries. The use of somewhat different tasks in Belgium compared to Norway, and Australia, possibly affected our main results. The separate analyses for tasks 2 and 3 show lower ICCs for the tasks performed only in Belgium. Thus, it is possible that our reliability indices would have been even higher if the tasks performed in Norway and Australia were performed by all participants. In future studies, we recommend using the tasks performed in Norway and Australia, as they have better reliability. Furthermore, our study population was not representative of the entire unilateral CP population. Population-based studies indicate that about 87% of children with unilateral CP are classified in MACS levels I to II, while about 13% are classified in MACS level III. In our study, only two children (3%) in MACS level III were included. Although MACS levels do not reveal whether a child has mirror movements or not,[7] it would have been advantageous for the generalizability of our results to have more children in MACS level III included in our study. Future research is needed to investigate the reliability of the Woods and Teuber scale of children in MACS level III.

Conclusion

This study demonstrates high inter- and intrareliability of the Woods and Teuber scale for scoring mirror movements in children and adolescents with unilateral CP. The observation-based Woods and Teuber scale has excellent clinical utility and does not require specific

equipment, making it a feasible and useful instrument for scoring mirror movements in research and clinical practice. Standardized administration guidelines for the Woods and Teuber scale need to be developed to enable comparison of outcomes in future research.

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Supporting information

The following additional material may be found online:

Video S1: Woods and Teuber level 0.

Video S2: Woods and Teuber level 1

Video S3: Woods and Teuber level 2a)

Video S4: Woods and Teuber level 2b)

Video S5: Woods and Teuber level 3

Video S6: Woods and Teuber level 4

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Table 1: Demographic information for participants and mean Woods and Teuber scores for the participants are shown

	Participating country			
	Norway	Australia	Belgium	Total
Participants, *n* (%)	19 (28)	23 (34)	26 (38)	68 (100)
Age, mean (SD), y:mo	16:3 (1:9)	10:1 (2:1)	11:0 (2:7)	12:2 (3:5)
Right more-affected hand, *n* (%)	10 (63)	17 (74)	14 (54)	41 (60)
Male, *n* (%)	9 (47)	10 (43)	12 (4)	31 (46)
MACS level, *n* (%)				
I	4 (21)	5 (2)	11 (42)	20 (29)
II	14 (74)	18 (78)	14 (54)	46 (68)
III	1 (5)	0	1 (4)	2 (3)
AHA unit, mean (SD)	66.2 (16.3)	52.2 (17.0)	66.9 (19.7)	61.7 (19.0)
Woods and Teuber score, mean (SD)				
Rater A				
Rating 1	8.3 (9.5)	7.5 (5.3)	4.8 (4.0)	6.7 (6.5)
Rating 2	7.8 (9.3)	6.4 (5.5)	4.7 (4.3)	6.2 (6.4)
Rater B				
Rating 1	9.1 (7.4)	9.4 (4.5)	7.8 (4.1)	8.7 (5.3)
Rating 2	8.3 (7.8)	8.4 (4.5)	7.0 (3.9)	7.9 (5.4)
Rater C				
Rating 1	8.7 (9.6)	9.8 (5.9)	6.0 (4.2)	8.1 (6.5)
Rating 2	7.5 (8.0)	7.6 (5.1)	4.4 (4.0)	6.4 (5.8)

MACS, Manual Ability Classification System; AHA, Assisting Hand Assessment.

Table 2: Intraclass correlation coefficients (ICCs) for the Woods and Teuber scale when classifying mirror movements in the more-affected and less-affected hand

	Total	More-affected hand				Less-affected hand			
	score	Total	Task 1	Task 2	Task 3	Total	Task 1	Task 2	Task 3
Variance component									
Between participants	33.44	8.53	1.29	1.06	1.01	10.83	1.38	1.25	1.28
Between raters	0.74	0.19	0.03	0.01	0.03	0.18	0.02	0.02	0.02
Residual	2.93	1.20	0.23	0.23	0.27	0.95	0.18	0.20	0.23
Total	37.11	9.93	1.54	1.31	1.31	11.95	1.58	1.47	1.53
Reliability ICC									
Interrater	0.90	0.86	0.84	0.81	0.77	0.91	0.87	0.85	0.84
Intrarater	0.92	0.88	0.85	0.82	0.80	0.92	0.89	0.86	0.85

The table shows the variance components included in the equations as well as the resulting inter- and intrarater reliability, in terms of ICCs, for the Woods and Teuber total score (overall inter- and intrarater reliability), for the more-affected and less-affected hand and for each task.

Table 3: Variance components included in the equations and resulting inter- and intrarater reliability intraclass correlation coefficients (ICCs) for the various Woods and Teuber tasks performed

	More-affected hand					Less-affected hand				
	All	Norway and Australia		Belgium		All	Norway and Australia		Belgium	
	Task 1	Task 2	Task 3	Task 2[a]	Task 3[b]	Task 1	Task 2	Task 3	Task 2[a]	Task 3[b]
Variance component										
Between participants	1.29	1.39	1.14	0.51	0.73	1.38	1.48	1.51	0.48	0.73
Between raters	0.03	0.01	0.01	0.05	0.08	0.02	0.02	0.01	0.03	0.04
Residual	0.23	0.21	0.26	0.25	0.25	0.18	0.23	0.22	0.17	0.23
Total	1.54	1.61	1.42	0.80	1.07	1.58	1.72	1.74	0.68	1.01
Reliability ICC										
Interrater	0.84	0.86	0.81	0.63	0.69	0.87	0.86	0.87	0.71	0.73
Intrarater	0.85	0.87	0.82	0.69	0.76	0.89	0.87	0.87	0.75	0.77

Task 1, fist opening and clenching (performed in all countries). Task 2, repetitive tapping of the index finger on the thumb (performed in Norway and Australia). Task 3, simultaneously tapping the fingers on the table (performed in Norway and Australia). [a]Opposition of four fingers sequentially to the thumb (performed in Belgium). [b]Sequentially tapping the fingers on the table (performed in Belgium).

[Figure legend]

Figure 1: Mean total scores and 95% confidence intervals (CIs) of Woods and Teuber scale scores for both hands for the three tasks for each combination of time point (rating 1 and 2), rater (A, B, and C), and country (Norway, Australia, and Belgium).