Reliability of kinematic measures of functional reaching in children with cerebral palsy

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AIM The determination of rehabilitation effectiveness in children with cerebral palsy (CP) depends on the metric properties of the outcome measure. We evaluated the reliability of kinematic measures of functional upper limb reaching movements in children with CP.

METHOD Thirteen children (ten females, three males) with spastic hemiplegic, diplegic, or quadriplegic CP affecting at least one arm (mean age 9y, SD 1.6y; range 6–11y; Manual Ability Classification System [MACS] levels II–IV) were evaluated three times over 5 weeks. The kinematics of the more affected arm reaching to grasp a $2cm^3$ block placed at three distances from the body midline were analysed. The reliability (test–retest) of six kinematic variables (endpoint trajectory straightness and smoothness, trunk displacement, elbow extension, shoulder horizontal adduction, and shoulder flexion] was tested and expressed as intraclass correlation coefficients (ICC, model 2,K) and 95% confidence intervals.

RESULTS Trajectory smoothness, trunk displacement, elbow extension, and shoulder flexion (far target) had the highest ICCs (0.82–0.95). Other kinematic variables had moderate ($0.50 \leq ICC \leq 0.81$) or low (0.17–0.38) reliability. Test–retest reliability was task dependent, as reaches required different degrees of trunk displacement and joint excursion.

INTERPRETATION Kinematic variables can be used as outcomes in clinical trials to test upper limb intervention effectiveness on motor performance and movement quality. As kinematic variables are task specific, reliability should be interpreted in the context of task requirements.

Cerebral palsy (CP) encompasses a large number of non-progressive impairment syndromes arising from brain lesions or abnormalities in early development (fetus or infant).[1] As the definition implies, children with CP have a variety of symptoms spanning sensorimotor, cognitive, and social domains. In CP, brain injury occurring during periods of high neuronal plasticity and adaptability, when projections from damaged central nervous system areas have not yet reached their final targets, may interfere with essential processes of neural maturation.[2] Although early neuronal organization facilitates motor skill acquisition ('adaptive plasticity'), this same capacity may lead to the development of atypical or alternative movement synergies interfering with typical development ('maladaptive plasticity'[3]), as is often seen in children with CP.[4] Further, atypical movement strategies or motor compensations may be reinforced with practice and empower an individual because they result in successful task achievement. However, they may interfere with the acquisition of more desirable movement patterns and mask real deficits.[5] Rehabilitation approaches such as constraint therapy and task-specific training purport to stimulate cortical neuroplasticity in a way that might encourage more normal skilled movement.[6]

Judgement of therapeutic effectiveness in reducing CP symptomatology is linked to the outcome measures chosen to evaluate change.[7] Outcome measures should reflect the specific disabilities targeted by the intervention.[8] Motor outcomes used in clinical trials in the form of checklists measure whether or not a task is accomplished but not how well it is performed (i.e. movement quality).[9,10] For better assessment of compensatory movements, evaluation of treatment effectiveness should include measures of both motor performance and movement quality.[11] For the upper limb, clinical scales, such as the Quality of Upper Extremity Skills Test (QUEST)[12] and the Melbourne Assessment of Unilateral Upper Limb Function,[13] permit subjective assessment of some elements of movement quality using continuous scales. However, information about upper limb movement gained from clinical instruments may be enhanced, when complemented by information from objective measures of movement quality derived from kinematic analysis.

Kinematic analysis can provide detailed data about movement patterns and their variability that can help an investigator relate changes in goal attainment to quantitative changes in movement quality. Kinematic gait analysis is the criterion standard for lower limb intervention effectiveness in children

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with CP.[14] However, kinematic analysis of upper limb movement in children with CP is used less often because of uncertainty about its reliability in this population.[15,16] Based on their study of joint trajectories used for reaching tasks in one child, Fitoussi et al.[17] concluded that kinematic analysis provides information about movement patterns that is not captured using clinical measures. Mackey et al.[18] reported moderate to high levels of repeatability of joint waveforms using multiple correlation analysis during hand-to-head and hand-to-mouth movements in children with CP. However, to date, no study has rigorously addressed kinematic reliability using intraclass correlation coefficients (ICCs). Our goal was to identify kinematic variables that could be used as reliable outcome measures in a future randomized clinical trial of upper limb reaching interventions in children with CP. The kinematic task investigated here is but one of several possible tasks that could be used to quantify reaching movement quality. We measured endpoint trajectory straightness and smoothness but not endpoint path, as it would be unreasonable to expect that children with CP would all use some ideal endpoint path for reaching. On the other hand, physical optimization rules would suggest that the nervous system would tend to make smoother and straighter movements by whatever (interjoint) means available. Further, in typically developing children, the end-state arm position when the task is achieved has been shown to provide the most accurate measurement of three-dimensional (3-D) kinematics in the upper limb.[19] The kinematic outcomes of this study are necessarily specific to the task chosen, as the number of possible tasks that could be used to measure upper limb movement is infinite.

What this paper adds

- Therapists can measure kinematic variables to evaluate motor performance and movement quality of upper limb reaching tasks.
- Depending on the task studied, some kinematic variables describing upper limb movement quality have high test–retest reliability.

METHOD

Study participants were 13 children with spastic CP aged from 6 to 11 years who had sensorimotor impairments in at least one arm, were able to sit unsupported, and had cognitive skills sufficient to understand instructions. Children with disorders such as ataxia, chorea, pain, or orthopaedic problems affecting the arm, neck, or trunk, including elbow or shoulder contractures greater than 10°, were excluded. Children were recruited from five Quebec rehabilitation centres (MacKay Centre, Centre de réadaptation Marie Enfant, Jewish Rehabilitation Hospital, Shriners Hospital, and Centre de réadaptation La ResSource). Children and families signed consent forms approved by institutional review boards of McGill University, Ste Justine Hospital, and the Centre de recherche interdisciplinaire en réadaptation. The level of upper limb functional severity was classified with the Manual Ability Classification System (MACS; Table I) – a five-level ordinal scale classifying the ability of children aged from 4 to 18 years to manipulate objects during daily activities. A MACS level I score indicates that the child handles objects easily and successfully, and level V indicates that the child cannot handle objects and is severely limited in the performance of even simple actions.[20]

Table I: Demographic and clinical characteristics of the children in the study

Child	Sex	Age (y)	Impairment distribution	Most affected upper limb	MACS
1	M	11	Hemiplegia	Right	IV
2	F	9	Hemiplegia	Right	III
3	F	8	Quadriplegia	Left	IV
4	M	10	Hemiplegia	Left	II
5	F	11	Hemiplegia	Right	III
6	F	9	Hemiplegia	Left	IV
7	F	6	Hemiplegia	Right	II
8	F	7	Quadriplegia	Left	III
9	F	9	Hemiplegia	Right	II
10	F	9	Hemiplegia	Right	IV
11	F	10	Hemiplegia	Left	II
12	F	7	Diplegia	Left	III
13	M	11	Hemiplegia	Left	II
Mean (SD)		9 (1.6)			

MACS, Manual Ability Classification System for Children with Cerebral Palsy 4–18 years.

Functional reaching task

To characterize reaching movement during a functional activity, a simulated feeding task was used. Children sat on a chair with their feet supported on the floor or a bench in front of a table adjusted to elbow height. In the initial position, before beginning each trial of the functional reaching task, efforts were made to maintain the child's hand 5cm from the chest at sternal height, with fingers straight, index finger aligned with body midline, thumb slightly abducted, wrist and shoulder in neutral positions, elbow flexed about 90°, and forearm pronated. The same set-up was used for typically developing children in previous studies.[21,22] Children were instructed to reach and grasp a 2cm^3 wooden block when verbally cued and to bring it towards the mouth as if eating food. Movements were self-paced and made with the more affected arm (see Table I). The block was placed on target positions located on the table at three distances from body midline (close target, T1: two-thirds arm's length; middle target, T2: 1 arm's length; far target, T3: one and two-thirds arm's length; Fig. 1a). Target distances were based on the child's arm length, defined as the distance from the medial axillary border to the distal wrist crease with the elbow extended.

Children were evaluated three times over 5 weeks (assessment 1, 0wk; assessment 2, 2.5wks; assessment 3, 5wks) by the same evaluator. During this period, children did not receive any physical rehabilitation interventions. In each assessment, kinematic data were recorded with an Optotrak 3020 (Northern Digital, Inc., Waterloo, ON, Canada) or a Vicon motion analysis system (Vicon, Los Angeles, CA, USA) at 100Hz. Data from 30 trials were collected in blocks of 10 trials per target, presented randomly. Trials were discarded if the child had trouble grasping or dropped the object (<2% of trials).

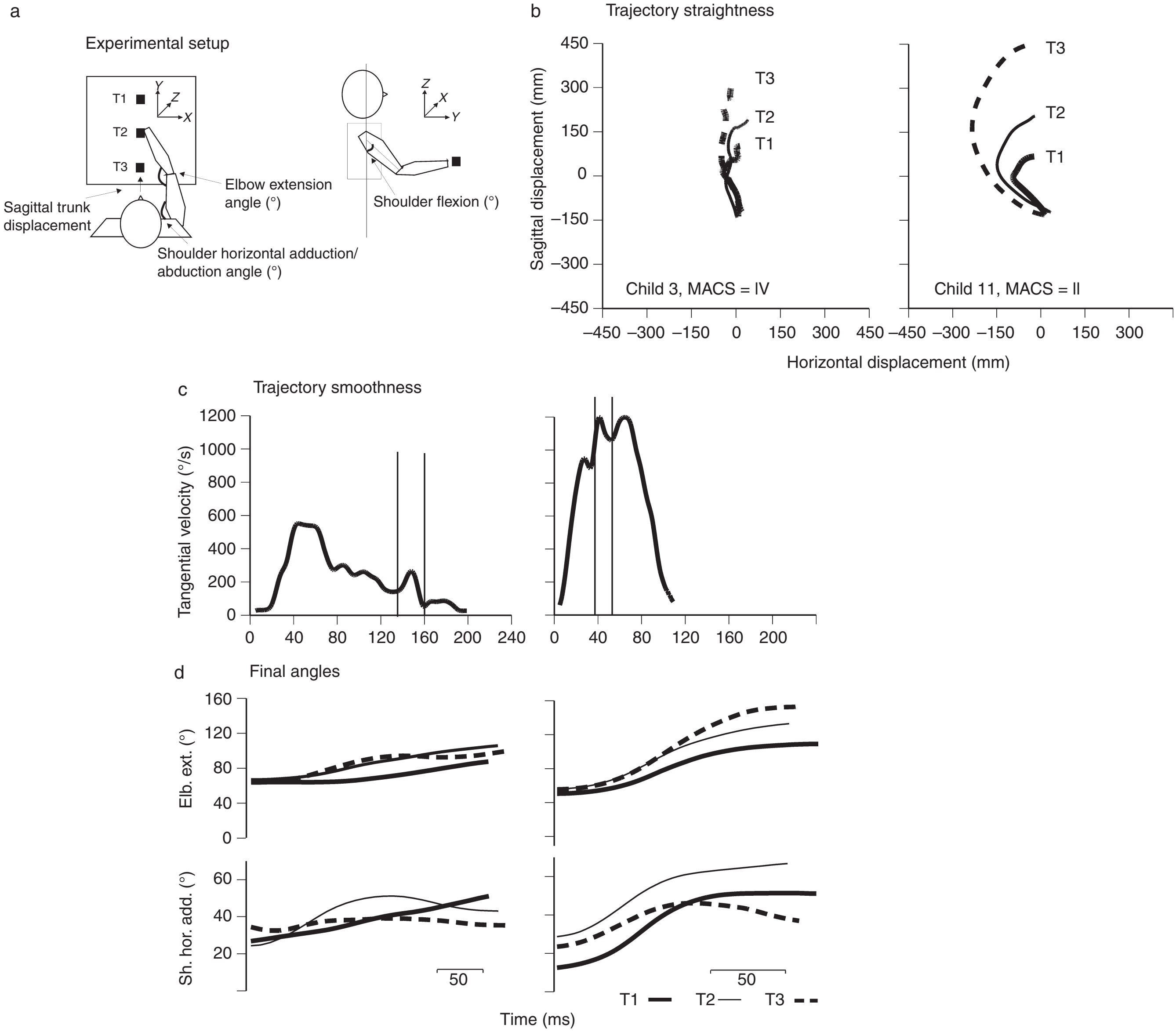

Figure 1: (a) Experimental set-up of the task used for kinematic analysis from a top-down (left) and sagittal (right) view, with definition of variables analysed. Objects were placed at three distances (T1, two-thirds arm's length; T2, arm's length; T3, one and two-thirds arm's length) from the child's body. The task was to reach and grasp the object and bring it to the mouth region as in self-feeding. Only the reach-to-grasp component was analysed. (b) Mean endpoint trajectories of two children with Manual Ability Classification System (MACS) levels of IV (left) and II (right) for reaches to close (T1 – thick solid lines), middle (T2 – thin solid lines), and far targets (T3 – dashed lines). (c) Mean endpoint tangential velocity profiles of the same two children for reaches to T2. A movement unit was defined as a local maximum velocity preceded and followed by increasing and decreasing values, respectively, for at least 20ms (parallel lines). (d) Mean final angles of elbow extension (Elb. ext.) and shoulder horizontal adduction (Sh. hor. add.) for reaches to each target as defined in (a).

Infrared light-emitting diodes or reflective markers were placed on the following arm and trunk anatomical landmarks and reference points: index finger middle phalanx (defined as the arm endpoint), thumb proximal phalanx, distal end of second metacarpal, radial styloid process, lateral epicondyle of elbow, ipsilateral acromion, sternal manubrium (trunk endpoint), contralateral acromion, and lateral to the ipsilateral iliac crest. Marker positions were standardized across assessments to improve reliability.

Data analysis

Only the reach-to-grasp kinematics were analysed. Positional (*x*, *y*, *z*) data were low-pass filtered (cut-off 10Hz) and used to plot 3-D trajectories. Arm endpoint and trunk tangential velocities were computed from the magnitude of the velocity vector obtained by differentiation of positional data. Arm endpoint tangential velocity traces were used to determine movement beginning (hand on chest) and end (time of grasping). Movement beginning and end were defined as the times at which endpoint tangential velocities exceeded and remained above, or fell and remained below, 5% of the maximal velocity. Endpoint trajectory and joint kinematic data were measured in the same segment of the reaching movement, as defined by the endpoint tangential velocity.

The reliability of kinematic variables previously reported to characterize mature reaching patterns in typically developing children was tested:[19,21,22] endpoint trajectory straightness and smoothness, trunk displacement, elbow absolute angle, shoulder horizontal (horizontal abduction/adduction), and sagittal plane movement (flexion/extension). Kinematic measures of both performance (i.e. trajectory characteristics) and movement quality (i.e. joint angular excursions) were included.[23] Endpoint trajectory straightness was determined by the index of curvature (IC), defined as the ratio of the actual endpoint path length to that of a straight line joining initial and final positions, where a straight line and semicircle have indices of 1 and 1.57 respectively. Endpoint trajectory smoothness was measured as the number of peaks (movement units) in the endpoint tangential velocity. A movement unit was defined as a local maximum velocity preceded and followed by increasing and decreasing values respectively, for at least 20ms (see Fig. 1c).[24] Trunk movement was computed as forward (sagittal) displacement in millimetres of the sternal marker (Fig. 1a). Final arm joint angles at the time of object grasping (movement end) were measured because these are less variable than angle paths.[25] Elbow and shoulder angles were computed by vectors joining markers placed on the wrist, elbow, ipsilateral shoulder, and iliac crest. The elbow angle was formed by the vectors between markers placed on the wrist, lateral epicondyle, and ipsilateral acromion process, where the fully extended arm was 180°. Shoulder horizontal abduction/adduction was measured as the horizontal projection of the angle between vectors formed by the ipsilateral and contralateral shoulder markers and the ipsilateral shoulder and elbow markers, where 0° corresponded to the arm outstretched in the frontal plane. Shoulder flexion was calculated with vectors formed by markers placed on the lateral epicondyle, ipsilateral acromion, and lateral iliac crest, where 0° was defined as the arm alongside the body.

Statistical analysis

The sample size of 13 participants was estimated, taking as the null hypothesis (ρ=0) the value of 0.70 representing moderate reliability compared with the alternative or tested hypothesis (ρ=1) of 0.90 representing excellent reliability.[26] Descriptive statistics (mean, SD) characterized kinematic variables for each child, assessment, and target. To determine test–retest reliability, an ICC model (2,K) and 95% confidence intervals (CIs) were used. ICCs were based on two-way random effects analysis of variance (ANOVA). This model was judged as most appropriate, as it accounts for the random effects of participants, the average rating of the dependent variable at each time period, and residual effects, as well as the number of observations.[27]

RESULTS

Effects of target distance on reaching performance

Typical endpoint trajectories and their endpoint tangential velocities as well as joint angle profiles in two children with variable severity of upper limb impairment (MACS IV, II) are shown in Fig. 1b to d. Targets required different amounts of arm and trunk displacement (Table II). Trunk displacement and arm angles were smaller for T1 (close target) reaches than for the other targets. Endpoint trajectories were more curved to orientate the hand in a frontal plane for grasping the closer object. Reaches to T2 (middle target) required minimal trunk displacement in typically developing children.[21] However, in children with CP, the amount of trunk displacement and arm movement for T1 and T2 depended on the severity of the arm impairment. Grasping T3 (far target) required trunk displacement and larger arm joint excursions. T3 endpoint trajectories were straighter than those for T1 and T2 because grasping this target required a more sagittal hand orientation. Shoulder horizontal abduction/adduction angles were small and relatively similar across targets owing to the midline object placement (Table II).

Test–retest reliability of reach-to-grasp kinematics

Reliability coefficients were as follows: poor, <0.50; moderate, 0.50–0.74; good/substantial, 0.75–0.90; and excellent/almost perfect, >0.90.[26] Overall, ICCs for all kinematic variables and all three targets had moderate to excellent reliability (0.50≤ ICC ≤0.95) except for shoulder horizontal abduction/adduction for T1 and shoulder flexion for T2 (Table II). Mean (SD) differences between pairs of measurements are shown in Table III.

For T1, trunk displacement had excellent reliability (ICC=0.92), trajectory smoothness and elbow angle had good reliability (ICC>0.80), and endpoint trajectory straightness and shoulder flexion had moderate reliability (ICC>0.58). For reaches to T2, trunk displacement and elbow angle had excellent reliability (ICC>0.90), trajectory straightness and smoothness reliability were good (ICC>0.75), and shoulder horizontal abduction/adduction angle was moderately reliable (ICC=0.50). For reaches to T3, trajectory smoothness, elbow angle, and shoulder flexion angle had excellent reliability (ICC>0.90). Trunk displacement and trajectory straightness had good reliability (ICC>80), and shoulder horizontal abduction/adduction had moderate reliability (ICC=0.51). ICC CIs were generally small for those variables with good to excellent reliability for T2 and T3, but less so for reaches to T1 (Table II). Trunk displacement and elbow angles had the highest test–retest reliability coefficients and the smallest CIs (95%).

DISCUSSION

Determination of movement quality requires reliable measurement of movement patterns as well as their deviation from typical movement patterns. It is important, therefore, to use measures that are able to detect the true variance of the movement while still being reproducible. We investigated the reliability of kinematic variables describing reaching movement

Table II: Test–retest reliability of kinematic data (mean SD) for reaches to targets placed at three different distances in three separate assessment periods (A1, A2, A3) for 13 children

	Target 1, mean (SD)			Target 2, mean (SD)			Target 3, mean (SD)			ICC, SEM (95% CI)		
Kinematic variables	A1	A2	A3	A1	A2	A3	A1	A2	A3	Target 1 (close)	Target 2 (middle)	Target 3 (far)
Trajectory straightness (IC)	1.66 (0.44)	1.56 (0.19)	1.54 (0.23)	1.45 (0.22)	1.41 (0.14)	1.40 (0.16)	1.32 (0.13)	1.35 (0.13)	1.31 (0.14)	**0.59,** 0.17 (−0.05, 0.86)	**0.76,** 0.08 (0.40, 0.92)	**0.81,** 0.06 (0.52, 0.94)
Trajectory smoothness (no. of peaks)	3.4 (1.3)	3.8 (1.0)	3.2 (0.9)	3.6 (1.3)	3.7 (1.7)	3.6 (1.5)	4.3 (2.1)	4.2 (1.6)	3.5 (1.4)	**0.82,** 0.46 (0.53, 0.94)	**0.88,** 0.52 (0.69, 0.96)	**0.91,** 0.46 (0.78, 0.97)
Trunk displacement (mm)	26 (31)	35 (49)	39 (41)	61 (62)	65 (61)	71 (70)	196 (76)	184 (79)	194 (65)	**0.92,** 10.81 (0.80, 0.97)	**0.95,** 13.65 (0.88, 0.98)	**0.86,** 27.17 (0.66, 0.96)
Elbow angle (°)	71 (19)	77 (19)	77 (20)	95 (25)	96 (19)	92 (26)	104 (33)	113 (24)	111 (31)	**0.87,** 7.06 (0.67, 0.96)	**0.94,** 5.31 (0.85, 0.98)	**0.91,** 8.78 (0.76, 0.97)
Shoulder horizontal adduction (°)	45 (14)	47 (21)	38 (15)	47 (13)	51 (20)	42 (12)	36 (13)	41 (17)	37 (11)	**0.17,** 15.35 (−1.12, 0.73)	**0.50,** 11.05 (−0.28, 0.83)	**0.51,** 9.66 (−0.24, 0.84)
Shoulder flexion (°)	44 (13)	42 (8)	46 (11)	60 (8)	58 (8)	62 (9)	76 (17)	79 (18)	79 (18)	**0.71,** 5.93 (0.23, 0.91)	**0.38,** 6.32 (−0.63, 0.81)	**0.93,** 4.76 (0.81, 0.98)

Numbers in bold are ICCs. IC, index of curvature; ICC, intraclass correlation coefficient; SEM, standard error of measurement; CI, confidence interval.

Table III: Mean (SD) absolute differences between values for the three assessment times (A1, A2, A3) for each of the kinematic variables

	Target 1			Target 2			Target 3		
Mean difference	A1 vs A2	A1 vs A3	A2 vs A3	A1 vs A2	A1 vs A3	A2 vs A3	A1 vs A2	A1 vs A3	A2 vs A3
Trajectory straightness (IC)	0.10 (0.11)	0.12 (0.12)	0.02 (0.06)	0.04 (0.05)	0.04 (0.06)	0.003 (0.04)	0.03 (0.03)	0.02 (0.03)	0.04 (0.04)
Trajectory smoothness (no. of peaks)	0.41 (0.27)	0.25 (0.25)	0.65 (0.29)	0.09 (0.38)	0.06 (0.28)	0.15 (0.30)	0.92 (0.33)	0.77 (0.39)	0.68 (0.21)
Trunk displacement (mm)	9.60 (8.19)	12.5 (8.20)	2.85 (4.80)	3.77 (10.50)	9.69 (8.07)	5.92 (8.03)	12.60 (11.40)	2.00 (18.30)	10.60 (18.0)
Elbow angle (°)	5.15 (4.06)	4.40 (5.50)	0.77 (3.58)	1.80 (3.90)	2.54 (3.60)	4.39 (3.49)	8.69 (6.6)	6.23 (4.19)	2.46 (5.70)
Shoulder horizontal adduction (°)	2.46 (6.87)	5.54 (5.99)	8.00 (6.57)	3.46 (5.11)	4.92 (4.84)	8.39 (5.66)	4.54 (4.98)	1.08 (3.99)	3.46 (5.16)
Shoulder flexion (°)	2.08 (3.97)	0.12 (3.39)	1.97 (2.72)	1.83 (3.14)	1.42 (2.49)	3.25 (3.19)	2.58 (2.54)	2.83 (3.40)	0.25 (3.42)

SE, standard error; IC, index of curvature.

using ICCs and 95% CIs. The variables that rated consistently highly across the three targets were trajectory smoothness, trunk displacement, and elbow extension. Shoulder abduction/adduction was not reliable at all, whereas trajectory straightness was reliable for reaches to the two farthest targets (T2, T3) and shoulder flexion was reliable only for reaches to the far target.

Most kinematic variables evaluated had good reliability, with ICCs above 0.75. The acceptable level of reliability depends on the measurement goal. If the purpose of the measurement is to describe movement behaviour, a lower reliability may be tolerated, especially if the source of the random variance is known. However, if the purpose is clinical decision-making or the demonstration of intervention effectiveness, reliability scores should be higher than 0.90.[26] Our goal was to identify kinematic variables that could be used as reliable outcome measures of a specific reaching task designed to be used in randomized clinical trials of upper limb interventions in children with CP. We took a less conservative approach and accepted reliability of 0.80 for two reasons. First, this study provides proof-of-principle of the feasibility of using kinematic variables for assessment and measurement of this task. Second, movements in children with CP are highly variable and distinct from those of typically developing children. This emphasized the need for an assessment approach that would adequately characterize alternative movement patterns. The variables that rated consistently above an ICC of 0.80 across the three targets were trajectory smoothness, trunk displacement, and elbow extension. Thus, we are confident that these three parameters will be reliable indicators of change in movement quality for this or a similar upper limb reaching intervention.

A previous study assessing the reliability of upper limb kinematics in children with CP[18] focused on within-session (internal consistency) and between-session reliability (test–retest, 1wk apart) of mean proximal and distal arm angle waveforms of two upper limb tasks performed by the more and less affected arms. Moderate r^2 values were obtained for between-session reliability for measures of the affected arm, possibly because of differences in initial arm position. In our study, we had similar difficulties in controlling the initial position, specifically of the shoulder, which invalidated the analysis of change in range of joint angle data. Thus, we reported only final angular positions. The differences in the task and type of statistical analysis in our and the previous study do not allow further comparisons.

Relationship to arm workspace

The reaching task was chosen to address upper limb movement deficits related to problems in self-feeding.[28,29] Three targets in the sagittal plane were used to investigate the effect of target distance on kinematic variables. Reliability coefficients varied according to the target distance. The lowest ICCs were computed for reaches to the nearest target, T1, and for shoulder horizontal abduction/adduction angles for all targets. The low ICCs may be explained by task-specific neural–biomechanical constraints.[30] For T1, reaching movements were shorter, gaze angle was different and smaller trunk displacement and arm joint rotations were required than for the other target distances. Differences in environmental conditions and sensory information may affect motor behaviour in children with CP.[31] In addition, the relatively higher reliability of kinematics of reaching to T2 and T3 may have been related to a more limited number of arm and trunk configurations used for reaches to the farther targets. It is important to note that during reach-to-grasp movements from sitting, children with CP use more trunk displacement than their typically developing peers.[32] As a decrease in excessive trunk displacement is associated with better upper limb activity,[33] the high reliability of trunk displacement will permit analysis of this parameter in intervention studies.

Shoulder angle measures were not as reliable as those of the elbow, as reflected in a higher between-measures variance (e.g. for T1, shoulder adduction=218 and elbow=100). The ICC represents the ratio of the sample variance to the total variance, measurement error, and number of participants. High ICCs and good reliability occur when the variance among the repeated tests is smaller than that between participants.

Finally, shoulder kinematic reliability may have been low because of the larger number of proximal compared with distal degrees of freedom used to stabilize the endpoint path.[25] There are three degrees of freedom at the shoulder (horizontal abduction/adduction, flexion/extension, rotation) compared with two at the elbow (flexion/extension, supination/pronation) and two at the wrist (flexion/extension, medial/ulnar deviation). Children had to reach and grasp the object in the body midline. As the hand initially was also in the body midline, the movement was performed primarily in the sagittal plane, which required a combination of elbow extension and shoulder flexion. Shoulder movements in the horizontal plane (shoulder horizontal abduction/adduction) were small and contributed little to the task. Thus, for this task, the shoulder flexion measure was more reliable than that of shoulder abduction/adduction. The ICC for shoulder flexion was higher than that of shoulder abduction/adduction, despite a similar between-participants variance because of a lower between-measures mean square measurement error. Thus, kinematic outcomes for horizontal shoulder movements for midline upper limb movements should be interpreted with caution. Further research is needed to address the test–retest reliability of shoulder horizontal angles for different upper limb tasks performed in different areas of the arm workspace.

Limitations

Kinematic variables are task specific so that reliability should be interpreted in the context of task requirements. Measurement reliability reported in this study can be generalized only for reaching and grasping objects placed in the body midline.

CONCLUSION

Kinematic analysis is a useful tool for investigating upper limb movement through objective description of movement quality for a specific task. Only reliable kinematic variables should be used as outcome measures in clinical trials aimed at evaluating the efficacy of upper limb interventions.

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