Original Research

Validating Accelerometry as a Measure of Arm Movement for Children With Hemiplegic Cerebral Palsy

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Background. For children with hemiplegic cerebral palsy (HCP), rehabilitation aims to increase movement of the affected arm. However, no validated measure objectively examines this construct in pediatric practice or daily life.

Objective. The objective of this study was to evaluate the criterion and known-groups validity of accelerometry as a measure of arm movement in children and adolescents with HCP.

Design. This was a prospective cross-sectional study.

Methods. Twenty-seven children and adolescents with typical development (3.4–13.9 years old) and 11 children and adolescents with HCP (4.7–14.7 years old; Manual Ability Classification System rating I or II) wore accelerometers on their wrists while engaged in 20 minutes of play, which included intermittent intervals of stillness and vigorous movement of the arms. Vector magnitude (VM) values identified the presence (VM > 2.0 counts per epoch) and absence (VM ≤ 2.0 counts per epoch) of arm movement for every 2-second epoch. Video was simultaneously recorded; each 2-second interval of footage was scored as "movement" or "no movement" for each arm.

Results. Agreement between accelerometry and video observation was greater than or equal to 81%, and the prevalence-adjusted and bias-adjusted κ value was greater than or equal to 0.69 for both groups of participants; these results supported the criterion validity of accelerometry. The ratio of nondominant arm movement to dominant arm movement measured by accelerometry was significantly greater in participants with typical development (mean [SD] = 0.87 [0.09]) than in participants with HCP (mean = 0.78 [0.07]) on the basis of 10 age- and sex-matched pairs; these results supported known-groups validity.

Limitations. The small sample size of the group with HCP prevented the stratification of data by age. Participants with HCP had high or moderately high function of the affected arm; hence, the findings do not apply to children and adolescents with more significant hemiparesis.

Conclusions. Accelerometry is a valid measure of arm movement in children with HCP and children without HCP. These findings contribute to the development of innovative upper limb assessments for children with hemiparesis.

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Hemiparetic cerebral palsy (HCP) is the most common form of cerebral palsy (CP), which is the leading cause of physical disability in childhood.[1,2] HCP is characterized by 1-sided impairments involving weakness, abnormal muscle tone, and decreased selective motor control in the affected limbs.[3] Children with HCP usually have some capacity for voluntary movement of the affected arm that can be enhanced through therapy.[4] Despite this capacity, these children often present with "developmental disregard" of the affected upper limb. This involves a tendency to disregard and not use the affected arm during daily life.[5–7] Thus, interventions often target increased functional use of the affected arm. However, most pediatric outcome measures involve eliciting the child's optimal capacity for arm use in clinical settings (eg, the Quality of Upper Extremity Skills Test [QUEST]), rather than measuring actual daily arm use. There are reported discrepancies between performance on such clinic-based tests and children's continued use of the affected arm in daily life.[7,8] Some measures do target children's arm use in natural environments.[8,9] However, these tools (eg, Pediatric Motor Activity Log-Revised) rely on subjective parent or child report, which is prone to recall bias, response bias, and high interresponder variation.[10] Early accelerometers, either embedded inside a toy[11] or placed on the arms,[12] were investigated as a means to collect objective information about arm movements in children. However, these studies measured movement during discrete, structured motor tasks rather than more spontaneous and natural play. There is still no validated objective measure of a child's affected arm movement during daily life.

Accelerometry is a tool with the potential to objectively quantify the amount of movement in the affected arm, relative to the unaffected arm, in children's natural environments. It could provide information missing from current clinic-based pediatric assessments. When validated, this technology could catalyze innovation in pediatric rehabilitation by providing a tool for objectively measuring and monitoring the quantity of movement of the affected arm outside the clinic. Further, accelerometry could improve accuracy in treatment plan execution, by allowing therapists to record the quantity of movement performed with the affected upper limb during each treatment. Although arm accelerometry has not yet been validated for these purposes in children, its validity as a measure of arm movement in adults with hemiparesis has been established. Uswatte et al[13] first provided evidence of its criterion validity, or its agreement with a gold standard measure, by comparing arm movement scores derived from accelerometry with videotaped observations of movement. Several subsequent studies and 2 systematic reviews further supported the validity of accelerometry-based arm movement ratios (ie, ratios of nondominant arm movement to dominant arm movement) as an index of real-world rehabilitative outcome in adults with hemiparesis.[14–16]

In contrast, there is a paucity of research on the validity of accelerometry as a measure of arm movement in children. The validity of accelerometry to measure arm movement in children with hemiparesis cannot be assumed based on the adult literature because there are notable differences between these 2 groups that could influence the validity. For example, there is a neurological distinction between adults with learned nonuse of the hemiparetic upper limb and children with developmental disregard, who lack motor memories and typical neural pathway development of the affected arm.[7,17] Further, it has been reported that children produce a higher frequency of nonfunctional arm movements compared with adults,[18] which could impact the meaning of pediatric arm movement ratios obtained through accelerometry. Although Sokal et al performed a preliminary analysis of the convergent validity of accelerometry in children with HCP, they found only a moderate correlation between accelerometry-based arm movement ratios and a clinical measure of arm function (Pediatric Arm Function Test), and no correlation between arm movement ratios and subjective reports of arm use (Pediatric Motor Activity Log-Revised scores).[18] No evaluation of criterion validity was performed, as was required to validate this tool in adults. Furthermore, no normative data were collected from children with typical development as a standard for comparison. A few pediatric studies have used accelerometry as an outcome measure in children with HCP, without reference to any foundational criterion or convergent validity testing. Gordon et al[19] and Coker-Bolt et al[20] both reported increases in arm movement ratios, as measured with accelerometry, in children with CP in response to therapeutic interventions. These studies support the responsiveness of the measure to intervention-related change; however, the criterion validity of accelerometry as a measure of arm movement in children has yet to be established.

As a first step toward developing an objective means to quantify the impact of interventions on daily arm movement in children, we examined the validity of accelerometry as a measure of arm movement in a pediatric population. We conducted our investigation in children, both with and without HCP, in a controlled laboratory setting. Accelerations of the arms, which indicated the presence of movement, were examined for both children with typical development and children with HCP during their performance of tabletop activities. The primary objective was to evaluate criterion validity, by comparing accelerometry's detection of arm movements with concurrently gathered video observations of arm movement. We hypothesized that the agreement between accelerometry and video observations would be high (ie, >80% agreement with a prevalence-adjusted, bias-adjusted kappa [PABAK] coefficient > 0.7) for both groups of children. As a secondary objective, known-groups validity, a type of construct validity that examines the ability to distinguish between 2 groups (eg, diagnostic groups), was evaluated by comparing accelerometry-derived arm movement ratios between age- and sex-matched children with and without HCP. We hypothesized that children with HCP would have lower arm movement ratios than children with typical development.

Methods

Participants

A prospective, cross-sectional study design was used involving children and adolescents with either typical development or HCP. Participants with typical development were recruited through emails sent to staff at the Lyndhurst Centre, Toronto Rehabilitation Institute—University Health Network. For participants with typical development, the following inclusion criteria were used: (1) 3 to 16 years old; and (2) no developmental condition or other diagnosis affecting the arms. Participants with HCP were recruited from previously established databases of children with HCP, in both Toronto, Ontario (the Ontario Brain Institute-funded CP-NET), and Edmonton, Alberta (participants of other studies whose parents provided consent to be contacted). For participants with HCP, the inclusion criteria were: (1) 3 to 16 years old; (2) presence of hemiparesis secondary to spastic CP, as confirmed by a medical doctor familiar with the child; (3) the ability to sit unsupported for more than 1 minute; and (4) a rating on the Manual Ability Classification System (MACS) of I to IV. Individuals with diagnoses associated with the production of involuntary arm movements, such as nonspastic CP (dyskinetic or ataxic) and uncontrolled seizures, were excluded, as were individuals with medical comorbidities affecting motor development or sensory function of the upper extremities. Individuals with upper extremity contractures were also excluded. Study approval was obtained from the Research Ethics Boards of the University Health Network, Bloorview Research Institute, and the University of Alberta.

Data Collection

All participants attended 1 testing session in a laboratory setting. The same researcher collected the data at both sites. The participants were engaged in upper limb activities with age-appropriate toys or tasks in a seated position for 20 minutes. The testing session was structured to include: 5 minutes of bimanual activities (eg, beading, foosball, card shuffling, making shapes with playdough), 5 minutes of unimanual activities (eg, drawing, coloring, completing a block puzzle, building a tower), and 5 minutes of self-chosen activities. Intervals of vigorous shaking and stillness of the arms were performed before and after each activity period. The participants were asked to keep still for 30 seconds, followed by 30 seconds of vigorous arm movement (ie, shaking maracas) and another 30 seconds of stillness. These intervals were included so that the sensitivity and specificity of the accelerometry data could be evaluated under a range of conditions, including both no arm movement and highly intense arm movement.

During the testing session, each participant wore 2 wireless triaxial accelerometers (Actigraph wGT3X-BT; Actigraph LLC, Pensacola, FL, USA), with 1 over the dorsal aspect of each wrist. Devices were set to sample accelerations at 10 Hz. Each participant's upper body movements were videotaped during the 20-minute play period with the camera positioned directly in front (at a 1-m distance). A laptop displaying a digital clock was visible in all video frames. The same laptop was used to initialize the accelerometers; hence the accelerometry and video data were aligned in time.

For descriptive purposes, all participants with HCP were administered the following clinical scales by a researcher who is also an occupational therapist.

MACS. The MACS is a scale used to classify children and adolescents with CP (4–18 years old) based on their level of object handling during daily activities.[21] MACS levels range from I ("Handles objects easily and successfully") to V ("Does not handle objects and has severely limited ability to perform even simple actions").[22] A researcher asked the parents questions about their child's or adolescent's daily arm use to determine the MACS level.

QUEST. The QUEST[23] measures the quality of a child's arm movements, and has been validated for use with children with CP (18 months to 8 years old).[24] The QUEST includes different domains of movement evaluation: dissociated movement, grasp, weight bearing, and protective extension. Total QUEST scores (as well as unilateral and bilateral subscores on the Grasp and Dissociated Movement scales) were collected and are reported here for all participants with HCP.

Modified Tardieu Scale. The Modified Tardieu Scale (MTS)[25] is a measure of spasticity, based on the muscle group's resistance to passive stretch at slow and fast speeds. Its interrater reliability in children with CP as young as 3 years of age has been established.[26] The MTS was measured for the affected wrist and elbow. The angle at which there was a "catch" during passive fast stretch was recorded, as was the severity of spasticity; grades ranged from 0 (= no resistance) to 5 (= joint was immobile to passive fast stretch).

Analysis of Video Data

Video data were observed offline by 1 of 2 researchers. Researchers observed each 2-second frame of video, providing a nominal score indicating the presence (score of 1) or absence (score of 0) of movement for each arm. These researchers did not view any accelerometry data either before or during the video analysis. To determine if the 2 researchers differed in their scoring of the video, the interrater reliability was evaluated. The researchers independently scored 7- to 10-minute samples of video from 4 participants with typical development and from 2 participants with HCP. Researchers' ratings (1 or 0) were compared using the PABAK value, which was chosen based on its adjustment for differences in the prevalence of conditions (eg, arm movement vs no arm movement) and systematic rater bias.[27] PABAK scores were interpreted as follows: 0.21 to 0.40 = fair; 0.41 to 0.60 = moderate; 0.61 to 0.80 = good; and 0.81 to 1.0 = excellent.[28,29]

Analysis of Accelerometry Data

Accelerometry data were uploaded from the monitors and processed with Actilife 6 software (Actigraph LLC, Pensacola, FL, USA). The software calculated vector magnitude (VM) values for each 2-second epoch. A VM (counts per epoch) is an estimate of the total amount of acceleration, combined across the 3 axes, calculated from the equation $\sqrt{(x^2 + y^2 + z^2)}$. VM values for each 2-second epoch were exported to Microsoft Excel (Microsoft Corp., Redmond, WA, USA) for further analysis.

Analysis of the accelerometry data required identification of a VM threshold to represent the divide between the presence and absence of arm movement. To determine the threshold setting to use with this age group, 3 potential VM threshold values were considered: (1) VM = 0 counts per epoch (default setting); (2) VM = 2.0 counts per epoch (threshold stated to maximize observer-accelerometry agreement in the measurement of adult arm movements[13]); and (3) the median optimal threshold value per group, calculated by conducting analyses of the receiver operating characteristic curve to identify the optimal threshold for each arm of each participant. The median rather than the mean was used because the distributions of optimal values for each group were skewed. The median optimal thresholds calculated for the group with typical development and the group with HCP were a VM of 7.1 counts per epoch and a VM of 4.9 counts per epoch, respectively.

To determine which VM threshold to use with the pediatric participants, receiver operating characteristic curve analyses were completed to determine how sensitivity and specificity varied at the 3 VM threshold settings, followed by calculation of the Youden Index (J): $J = [(\text{sensitivity}/100) + (\text{specificity}/100)] - 1$. We aimed to select the VM threshold at which the Youden Index was maximized. Mean values of the Youden Index for the 3 threshold settings were compared for each group separately using a 1-way analysis of variance. After the VM threshold was identified, each accelerometry data point for each participant was coded as movement or no movement.

Data Analysis

During the 20-minute activity period, each participant's arm movement ratio was calculated as the proportion of epochs that included movement in the nondominant (or affected) arm, divided by the proportion of epochs that included movement in the dominant (or unaffected) arm. Therefore, a value of 1.0 indicated that the amount of movement in the nondominant arm was equal to that in the dominant arm. A value less than 1.0 indicated that there was less movement in the nondominant arm, relative to the dominant arm, and a value greater than 1.0 indicated greater relative movement in the nondominant arm.

To evaluate criterion validity, agreement (%) between accelerometry data and video-based observer ratings was determined for each arm of each participant. Agreement was calculated as the proportion of total epochs in which the observer rating and accelerometry score for the absence or presence of movement matched. Mean values of agreement were then calculated for the dominant and nondominant arms for each group of participants (those with typical development and those with HCP). Within each group, the agreement calculated for the dominant and nondominant arms was compared with a matched-pair t test. PABAK coefficients were calculated to determine bias-adjusted agreement values. The mean PABAK coefficient was calculated for each group of participants (dominant and nondominant arms).

To evaluate known-groups validity, arm movement ratios calculated from accelerometry data were compared between sex- and age-matched (±1.0 year) pairs of participants with typical development and participants with HCP. For each participant with typical development, arm movement ratios were also calculated for the bimanual and unimanual play activities separately. Matched-pair t tests were used to compare arm movement ratios between the 2 groups of participants, and between the bimanual and unimanual conditions for the group with typical development. To determine if arm movement ratios varied with age in the group with typical development, the Pearson correlation coefficient was used.

Values are reported as mean [SD]. IBM SPSS version 24 was used for all statistical tests (IBM, Armonk, NY, USA). The Shapiro-Wilk test was used to test for normality. Because the distributions were normal and the data met the assumption of homogeneity of variance, parametric statistical tests (ie, matched-pair t tests) were used. The α level was set to .05.

Role of the Funding Source

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Results

Participant Characteristics

The group with typical development consisted of 27 participants (13 males, 14 females), ranging in age from 3.4 to 13.9 years (mean age = 6.3 [2.4] years). The HCP group consisted of 11 participants (4 males, 7 females) ranging in age from 4.7 to 14.7 years (mean age = 8.9

[3.4] years) (Tab. 1). Four of the 11 participants with HCP were tested in Edmonton, Alberta, Canada. MACS levels for all participants with HCP ranged from level I (7/11, or 64% of sample) to level II (4/11, or 36% of sample) (Tab. 2). Spasticity at the elbow and/or wrist was present in 8 of 11 participants with HCP; MTS grades ranged from 1 to 3 in these participants. Regarding the quality of upper extremity movements, total QUEST scores ranged from 54.9 to 99.1 of 100 (Tab. 2). Collectively, the clinical findings suggest that participants with HCP had a moderate to high level of function in the affected arm.

Interrater Reliability of Video Observation

The interrater reliability of the 2 researchers' video observations was excellent, with PABAK values of 0.83 [0.07] and 0.89 [0.07] for data sampled from participants with typical development and participants with HCP, respectively.

Establishment of Accelerometry-Based Threshold for Arm Movement

A VM threshold of 2.0 counts per epoch was identified as the threshold to differentiate between the presence (ie, VM > 2.0 counts per epoch) and absence (ie, VM ≤ 2.0 counts per epoch) of arm movement. The mean sensitivity, specificity, and the Youden Index for the group with typical development and the group with HCP at each VM threshold evaluated are reported in Table 3. No significant differences were found between Youden Index values at the 3 thresholds tested for the participants with typical development (df = 2,24; $F = 0.133$; $P = .876$) or for the participants with HCP (df = 2,8; $F = 0.150$; $P = .861$). Because there was no evidence suggesting that 1 of the 3 VM thresholds resulted in a greater Youden Index for either group of participants, a VM of 2.0 counts per epoch was chosen as the threshold to be consistent with other studies.[13,18]

Criterion Validity of Accelerometry

Among the participants with typical development, the mean agreement between accelerometry and video-based observation was 87.9% [4.3%] for dominant arm movements and 84.2% [4.3%] for nondominant arm movements (agreement for both arms = 86.1% [4.7%]). Agreement was significantly higher for dominant arm movements than for nondominant arm movements ($t_{26} = 5.189$; $P < .001$). PABAK coefficients were within the good range: 0.76 [0.09] for dominant arm movements and 0.69 [0.09] for nondominant arm movements.

Among the participants with HCP, the mean agreement between accelerometry and video-based observation was 89.5% [4.1%] for dominant (ie, unaffected) arm movements, and 81.8% [3.8%] for hemiparetic arm movements (agreement for both arms = 85.6% [5.0%]). Agreement was significantly higher for dominant (unaffected) arm movements than for hemiparetic arm movements ($t_{10} = 6.519$; $P < .001$). PABAK coefficients were within the excellent range: 0.89 [0.04] for dominant arm movements and 0.81 [0.04] for hemiparetic arm movements.

Known-Groups Validity of Accelerometry

The mean accelerometry-based arm movement ratio for the 27 participants with typical development was 0.89 [0.07], whereas that for the 11 participants with HCP was 0.77 [0.06]. When arm movement ratios were compared for 10 age- and sex-matched pairs of participants, the mean ratio of participants with typical development (0.87 [0.09]) was found to be significantly greater than the mean arm movement ratio of participants with HCP (0.78 [0.07]) ($t_9 = 2.769$; $P = .022$). The **Figure** shows the arm movement ratios for each pair of participants.

Within the participants with typical development, arm movement ratios during the bimanual play condition (0.90 [0.096]) were significantly higher than the arm use ratios calculated for the unimanual play condition (0.77 [0.189]) ($t_{26} = 3.42$; $P = .02$), further supporting the measure's validity. Arm movement ratios calculated for the participants with typical development did not correlate with age ($r = -0.258$; $P = .195$).

Discussion

Accelerometry was found to be a valid measure of arm movement in children and adolescents with and without mild to moderate HCP during tabletop activities in a laboratory setting. Good agreement between accelerometry data and video observations supported the criterion validity of the tool. Agreement was similar for the group with HCP and the group with typical development. Accelerometry was also found to have known-groups validity based on significant differences in the arm movement ratios between participants with HCP and without. Accelerometry shows promise as a potential outcome measure of arm movement for children and adolescents with HCP.

Arm accelerometry could contribute to innovations in current practice methods for the assessment and treatment of upper limb hemiparesis. By providing clinicians with accessible, objective quantification of affected arm movement, accelerometry could enable more accurate and less time-consuming evaluation of treatment progress and long-term maintenance of treatment outcomes. If used in the home and community environment, accelerometry would not be prone to the biases associated with assessments done in a clinic setting, in which children are aware they are being observed and thus can demonstrate greater than typical use of the affected arm. Many children with HCP demonstrate some disregard of their affected arm during daily life that is greater than would be expected based on their capacity for arm use alone.[5–7] In recognition of this phenomenon, accelerometry could provide a means of monitoring changes in daily arm movement and disregard that would not otherwise be detected by clinic-based assessments alone. The use of

Table 1.
Demographic Characteristics of Study Participants[a]

Participants	Characteristic	Value			
With typical development	Age (y)	3–5	6–7	8–10	11–14
	No. of participants	14	7	5	1
	Sex				
	Male	6 (5 R, 1 L)	3 (1 R, 2 L)	3(2 R, 1 L)	1 (1 L)
	Female	8 (8 R)	4 (3 R, 1 L)	2 (2 R)	
With hemiplegic cerebral palsy	Age (y)	3–5	6–7	8–10	11–14
	No. of participants	3	3	3	2
	Sex				
	Male			2 (1 R, 1 L)	2 (1 R, 1 L)
	Female	3 (1 R, 2 L)	3 (2 R, 1 L)	1 (1 L)	

[a]For participants in the group with hemiplegic cerebral palsy, the unaffected side was the dominant side and the hemiparetic or affected side was the nondominant side. L = left-hand dominant; R = right-hand dominant.

Table 2.
Performance on Clinical Measures of Participants With Hemiplegic Cerebral Palsy[a]

Participant	MACS Level	MTS Grade (Catch Angle [°])		QUEST Score				
		Wrist	Elbow	Dissociated Movement		Grasp		Total
				Bilateral	Unilateral	Bilateral	Unilateral	
1	I	0	2 (95)	92.0	84.4	90.7	88.8	84.4
2	I	0	0	100	100	96.3	92.6	99.1
3	II	2 (85)	2 (75)	64.1	40.6	51.9	22.2	62.1
4	I	0	0	100	100	79.6	77.8	90.7
5[b]	I	2 (20)	0	81.2	46.9	74.1	55.6	81.9
6[b]	II	2 (20)	2 (15)	67.9	50	61.1	48.2	54.9
7[b]	II	NT		86.7	42.2	55.6	29.6	73.0
8[b]	I	2 (30)	2 (55)	76.6	46.9	72.2	48.1	68.5
9	II	3 (90)	3 (5)	61.7	23.4	51.9	22.2	69.4
10	I	1 (170)	1 (97)	93.0	73.4	59.3	53.7	78.8
11	I	1[c]	1[c]	90.6	87.5	86.1	74.1	92.1

[a]MACS = Manual Abilities Classification Scale; MTS = Modified Tardieu Scale; NT = not tested (because of difficulty with having a participant assume a relaxed posture for passive movement testing); QUEST = Quality of Upper Extremity Skills Test.
[b]Participants tested in Edmonton, Alberta, Canada.
[c]No catch angle was found for this participant, but there was slight rigidity at the wrist and elbow passive range near end points; therefore, a spasticity grade >0 was assigned.

accelerometry within the home and community settings would require children to wear the accelerometers for multiple consecutive days; the feasibility of this has been demonstrated in previous studies using accelerometers to measure arm movement[18] and physical activity.[30] Accelerometry could also be used during treatment sessions to increase accuracy in therapists' monitoring of treatment plan execution (eg, recording the quantity of affected arm movement during each session) and the within-session responsiveness of clients to each treatment technique used. Another possible use of accelerometry is the monitoring and reinforcement of home exercise programs. Although such potential applications of accelerometry are valuable to ongoing innovation in pediatric rehabilitation, further psychometric testing in natural settings is required to confirm the tool's responsiveness.

Table 3.
Mean Sensitivity, Specificity, and Youden Index[a]

Threshold	Mean [SD]					
	Sensitivity (%)		Specificity (%)		Youden Index	
	TD Group	HCP Group	TD Group	HCP Group	TD Group	HCP Group
0	88.8 [6.0]	84.8 [7.2]	74.2 [15.6]	84.0 [9.0]	0.63 [0.14]	0.69 [0.11]
2.0	88.4 [5.8]	84.0 [6.9]	75.5 [14.5]	86.1 [8.6]	0.64 [0.14]	0.70 [0.09]
Optimal[b]	86.5 [6.2]	83.1 [7.3]	77.9 [13.6]	87.2 [7.9]	0.64 [0.13]	0.70 [0.09]

[a]HCP = hemiplegic cerebral palsy; TD = typical development.
[b]The optimal threshold was calculated to be a vector magnitude of 7.1 counts per epoch for participants with TD, and a vector magnitude of 4.9 counts per epoch for participants with HCP.

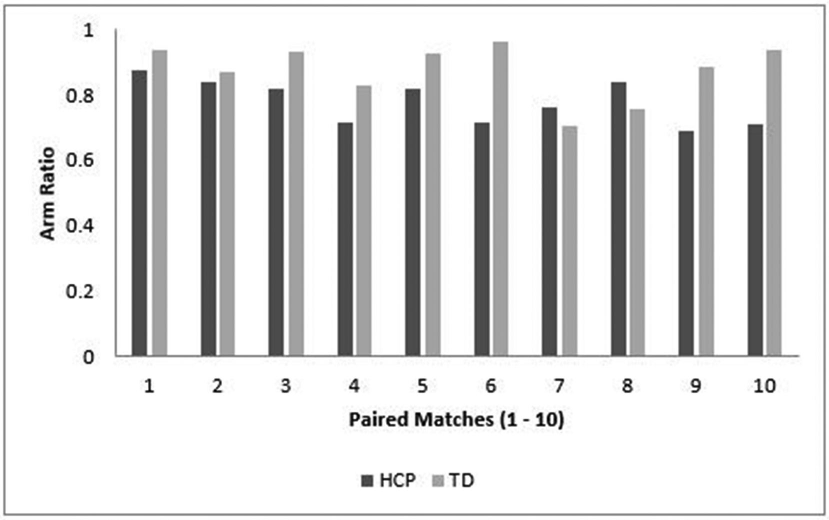

Figure.
Arm movement ratios of age- and sex-matched pairs of participants with typical development (TD) and participants with hemiplegic cerebral palsy (HCP).

The evaluation of the sensitivity and specificity of accelerometry to identify arm movement (Tab. 3) can provide insight into the direction of inaccuracy (ie, accelerometer identifying movement and observer identifying nonmovement for a given epoch, or vice versa). Among the participants with HCP, the values for sensitivity and specificity were similar (84% and 86%, respectively). This finding suggests that errors were made in both directions for the group with HCP. In contrast, the specificity reported for the group with typical development (76%) was smaller than the reported sensitivity (88%). These findings suggest that among children and adolescents with typical development, there was a tendency for the accelerometer to report movement when the observer reported no movement.

The levels of agreement between accelerometry and video observations for participants with and without HCP (81.8–89.5%) were lower than those previously published for adults after stroke (93%).[13] A possible explanation for the lower agreement found in children could be the tendency for children to present with more nonfunctional, smaller movements than adults, making video scoring of children more difficult. For example, in our participants from both groups, fidgeting with the hands was frequently observed. Sokal and colleagues concurred with this possibility, finding that their child participants moved their more-affected arm, even when using the less-affected arm, to a greater extent than adults did in previous studies.[18] The inclusion of small movements in the evaluation of agreement likely contributed to the lower agreement levels reported here. The study of adults by Uswatte and colleagues involved a systematic elimination of small movements (ie, movements with $<$2.5 cm in displacement length) from the analysis.[13] They found that observer-accelerometry agreement levels decreased by 9% when they included these small movements rather than excluding them from the analysis. They also found that

92% of intervals in which there was accelerometer-observer disagreement contained either small or nonfunctional arm movements.[13]

Here we have reported the ability of arm movement ratios derived from accelerometry to differentiate between children and adolescents with and without HCP. However, based on the small sample size we could not determine with adequate power whether accelerometry could discriminate between different levels of impairment within the HCP group. Similarly, the sample size was not large enough to evaluate convergent validity, or the degree to which accelerometry-based arm movement ratios correlate with another measure of upper limb function. We recommend that further analyses be conducted with a larger sample of children with HCP, including those with more severe impairments (ie, MACS levels III and IV), for the testing of this tool's convergent validity and its ability to distinguish between children with different levels of upper limb function.

Regarding arm movement ratios, we report the first published values found for children and adolescents with typical development during seated play activities. The arm movement ratios for each participant with typical development are reported by age and sex in the eAppendix (available at https://academic.oup.com/ptj), and can be used as reference data for future research and clinical applications. The mean arm movement ratio for the 27 participants with typical development, 0.89 [0.07], is within the range reported for healthy adults (0.79–1.1).[31] The arm ratio found here for children and adolescents with HCP, 0.77 [0.06], was lower than that found by Sokal et al for children with CP, using the same threshold of 2.0.[18] It is possible that our use of a smaller time period for observation (20 minutes vs >27 hours) contributed to this difference. We would expect arm ratios to increase if measured over longer time periods, due to inclusion of more resting time, during which both arms would have similar movement levels (eg, if both arms are still). Future research should include validation of arm movement ratios over longer periods of time, so more confidence can be placed in current estimates.

We found no correlation between arm movement ratios and age among our participants with typical development. However, arm movement ratios can be expected to decrease with age, based on the higher level of bilateral symmetrical arm use found in younger vs older children.[32] It is possible that the lack of significant differences found here could be due to the short data collection period (20 minutes) or the narrow age range sampled—all participants with typical development were 3 to 10 years old, except for 1 participant (Tab. 1). Thus, further research is required to document the arm ratios of children with typical development, not only for a greater age range and over longer periods of time, but also to increase the quantity of normative data available.

A controlled laboratory setting was used for data collection, which is both a strength and weakness of this study. By using a controlled laboratory setting, the internal validity of our results was increased by controlling for differences in how the accelerometers were worn and the activities performed by participants. However, the external validity of our findings was reduced because we did not test in natural environments, where accelerometers will potentially be used in the future. Further work is required to establish accelerometry's validity in natural settings, such as the child's home or a clinical environment, over longer periods of time.

The field of accelerometry, including the technology and analytical approaches, is continually evolving.[33] The triaxial accelerometer used in this study is currently the standard tool in the field of clinical accelerometry research; however, more sophisticated technological developments could result in greater measurement accuracy.

Conclusion

This study provides foundational evidence for the criterion and known-groups validity of arm accelerometry as a pediatric measurement tool, which could potentially be used to accurately monitor the quantity of affected arm movement in children with hemiparesis in both clinical and natural settings. With further examination of this tool's responsiveness and validity in natural environments, it could help to inform the evaluation and improvement of therapeutic interventions for HCP.

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Ethics Approval

Study approval was obtained from the Research Ethics Boards of the University Health Network, Bloorview Research Institute, and University of Alberta.

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Disclosures and Presentations

The authors completed the ICJME Form for Disclosure of Potential Conflicts of Interest and reported no conflicts of interest. Preliminary data from this study were presented at the 2017 Annual Conference of the Canadian Association of Occupational Therapists, June 21–24, 2017, Charlottetown, PEI, Canada.

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