Toward a More Comprehensive Assessment of School Age Children with Hemiplegic Cerebral Palsy

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ABSTRACT

BACKGROUND: Cerebral palsy (CP) is the leading cause of disability in children. While motor deficits define CP, many patients experience behavioral and cognitive deficits which limit participation. The purpose of this study was to contribute to our understanding of developmental delay and how to measure these deficits among children with CP.

METHODS: Children 5 to 15 years with hemiplegic CP were recruited. Cognition and motor ability were assessed. The brain injury associated with observed motor deficits was identified. Accelerometers measured real-world bilateral upper extremity movement and caregivers completed behavioral assessments.

RESULTS: Eleven children participated, 6 with presumed perinatal stroke. Four children scored below average intelligence quotient while other measures of cognition were within normal limits (except processing speed). Motor scores confirmed asymmetrical deficits. Approximately one third of scores indicated deficits in attention, behavior, or depression.

CONCLUSIONS: Our findings corroborate that children with CP experience challenges that are broader than motor impairment alone. Despite the variation in brain injury, all participants completed study procedures.

IMPLICATIONS: Our findings suggest that measuring behavior in children with CP may require a more comprehensive approach and that caregivers are amenable to using online collection tools which may assist in addressing the therapeutic needs of children with CP.

KEYWORDS: cerebral palsy, accelerometry, pediatric stroke, behavioral assessment

Highlights

- A combination of clinical assessment and caregiver-report can provide a more complete understanding of therapeutic needs.
- Measures of cognition that rely on intelligence quotients may not accurately represent cognitive capacity of children with CP.
- Providing electronic options for caregivers to complete assessments at their convenience is efficient for collecting information.

Introduction

Cerebral palsy (CP) is characterized by chronic motor deficits and is the most common disability identified during childhood.

Although CP is often present at birth, children are frequently not diagnosed until they are several years old.[1] While motor deficits are the most commonly described component of CP, non-motor disabilities are prevalent and can significantly impact the degree of disability experienced by the child and family.[2-4] Non-motor deficits such as inattention/hyperactivity, intellectual/learning disabilities, and behavioral/social challenges,[5-10] can result in substantial activity limitations.[11,12] Early identification of deficits is critical for securing applicable interventions to maximize the child developmental progress.[13,14] Because of the focus on motor impairment in CP, clinical assessment often focused on motor skills. However, children with CP are more likely to develop at least 1 problematic behavior that impedes daily functioning, such as aggression or depression.[2,4] When

behavioral delays are not identified in assessment, implementation of beneficial behavioral interventions is thwarted.[15] With timely intervention, costs associated with common deficits can be minimized; thus comprehensively assessing children with CP is an important target for the management of childhood disability.[16-19]

Magnetic resonance imaging (MRI) is the current diagnostic standard for identifying cerebral abnormalities that causes observed deficits in the brain.[13,20,21] However, neuroimaging requires children to remain still in the scanner, and because of the associated risks associated with sedation, it is not always practical.[22-25] The Gross Motor Function Classification System (GMFCS) is the most common scale used by pediatric providers to describe the level of gross motor impairment in children with CP, but inherently does not capture behavior or functional deficits that the child or caregivers experience in their day-to-day routines.[26] To more accurately describe the impact of CP, assessment should include both clinical evaluation and parent report. Additionally, the advancement of wearable technology has made it possible to use accelerometry to describe real-world activity in children with CP.[27]

The purpose of this study was to confirm prior reports of deficits associated with hemiplegic CP and describe the use of an assessment battery that combines motor and behavioral evaluation. Our approach to describing CP in children combined neuroimaging, real-world activity measured with accelerometry, clinical assessment of movement and cognition as well as parent-report measures of attention, depression, and behavior. We anticipate that these results will contribute to the understanding of the impact of CP on children and families.

Methods

The Institutional Review Board at Washington University School of Medicine approved this case series study. Participants (parents and their children with CP) attended up to 5 clinical visits 3 weeks apart (±3 days) lasting about 90 minutes. Each visit included clinical evaluation and parent report on survey measures. We utilized Research Electronic Data Capture (REDCap)[28] to facilitate survey completion. Participants were compensated for their time.

Participants

Children ages 5 to 17 years old with a diagnosis of hemiplegic CP were recruited for this study between May 2014 and December 2017 at Washington University School of Medicine and St. Louis Children's Hospital in St. Louis, MO by the first and last author (CH, ND). Children were all independently ambulating with a Gross Motor Classification Function System Score (GMFCS) of I or II. Children were excluded if they had previously participated in this study, received botulin toxin injections within the last 3 months, undergone orthopedic surgery within the last 6 months, or if children they had any known diagnosis also associated with motor impairment (eg, autism).

Measures

Visit 1: Cognitive and behavior assessment. Assessments were selected based on their psychometric properties and to minimize the amount of testing time required. Following informed consent, children completed a cognitive assessment including the Kaufman Brief Intelligence Test-2 (KBIT)[29] and the cognitive battery from the National Institute of Health (NIH) toolbox.[30] The KBIT measures verbal and nonverbal intelligence; a composite score below 85 indicates below-average intelligence, and a score below 70 indicates intellectual disability. The NIH toolbox assesses broader concepts linked to functional cognition, including language, attention, working and episodic memory, executive function, and processing speed. Most participants completed the NIH Toolbox using a tablet, however testing completed prior to August of 2016 used a desktop computer.

Simultaneously, parents completed several behavioral survey measures, including (1) the Conner's Continuous Performance Test (CPT),[31] a screening tool for attention related conditions, (2) the Child Behavior Checklist (CBCL),[32] an assessment of behavioral and emotional function, and (3) the Child Depression Inventory (CDI),[33] a screening tool for depression. All assessments were scored and compared to the normative data published and provided with each test and administrative manual.

The CPT evaluates attention-related behaviors in individuals aged 8 years and older often characteristic of Attention Deficit Hyperactive Disorder (ADHD) and other neurological conditions related to attention. Domains assessed include areas of inattentiveness, impulsivity, sustained attention, and vigilance. The CPT has reported good test-retest reliability (.67) and moderate discriminative validity (d = .10-.49).[31] The CBCL is a 101 item, parent report questionnaire that assesses behavioral and emotional problems in children 1.5 to 18 years of age. The CBCL has high test-retest reliability (.95-1.00) and content validity has been well established.[34] The CDI is a self-report assessment to identify behavioral signs of depression in children and adolescents. The validity of the CDI has been well established with moderate to high test-retest reliability.[35] The CDI can be an effective screening tool for children with chronic health conditions.[36]

Visit 2 to 5: Neuroimaging and motor assessment

Neuroimaging. To prepare children for neuroimaging, a 30-minute mock MRI scan was completed to familiarize children with the MRI environment. The mock scanner was outfitted with the MoTrak (Psychology Software Tools, Inc.) head motion tracking system, which teaches children to minimize head movement through real-time feedback. All MRI data were collected on a 3T Siemens Trio MRI Scanner (Siemens AG, Erlangen, Germany). Scans lasted approximately 90 minutes. Images collected during scanning included high-resolution T1-weighted, sagittal, magnetization-prepared rapid

gradient echo (MPRAGE) at 0.8 mm isotropic resolution. A trained neuroradiologist examined the T1 images to identify the location of cerebral injury (JSS).

Motor capacity. Children completed a brief motor assessment battery with a trained occupational therapist (CRH). Motor capacity was evaluated using the Melbourne Assessment of Unilateral Upper Limb Function-2 (MA).[37,38] The MA is a reliable and valid measure of functional skills.[37,39] Children were videotaped while they performed each of the 14 items of the MA which were later scored for range of motion, accuracy, fluency of movement, and dexterity. Two graduate students trained on the MA scored 25% of the MA videos (SS, SB) to confirm inter-rater reliability (ICC = 0.85, $P < .001$). One trained rater (SS or SB) scored the remaining videos. A score of 100% in each domain suggests no indication of motor deficits in the affected upper limb. Tapping speed, grip strength, and pinch strength were assessed 3 times bilaterally during visits 2 to 5. Tapping speed was measured in increments of 10 seconds using the Electronic Tapping Test (WPS, Torrance, CA). Grip strength was measured using the Jamar Plus+ Digital Hand dynamometer and lateral pinch strength was measured the Jamar Hydraulic Pinch Gauge (JLW Instruments, Chicago, IL). Tapping speed increases with age and is slightly higher in the dominant hand, with typically developing children in this age group completing approximately 40 to 60 taps using their dominant hand in 10 seconds.[40] Similarly, grip and pinch strength increase with age and ranges from approximately 30 to 75 pounds of force for grip and 7 to 13 pounds of force for pinch with little difference between hands.[41] Psychometric information is not available for these measures, so the impaired extremity was classified as the participant's nondominant hand for the purposes of this study.

Real-world movement was measured using accelerometry. The Actigraph wGT3X (ActiGraph, wGT3X-BT; ActiGraph LLC, Pensacola, FL) accelerometer was selected for this study because of its frequent use in pediatric research.[42] The accelerometers used were about the size of a typical wristwatch, weigh 19 g, have a battery life of approximately 25 days, and are water resistant up to 1 m. More detail about the accelerometry methods is previously published.[27]

Analysis

Behavioral measures were scored and compared to normative data to assess cognition (KBIT, NIH Toolbox) and to determine risk for developing attention related deficits (CPT), depression (CDI), and behavioral challenges (CBCL). Motor assessments were scored by trained graduate students in occupational therapy (SS, SB) and compared to normative data. Descriptive statistics summarized the demographic information and cognitive and behavioral measures using R Version 3.5.3.[43] Framewise Integrated Real-time MRI Monitoring (FIRMM) software was used to track head motion. Demographic information and

behavior measures were summarized using descriptive statistics. To ensure data quality, each participant wore the accelerometers for up to 5 complete days. Accelerometry data were visually inspected for quality and summarized using previously published methods.[27] Accelerometry data were processed using MATLAB Version 2015a[44] and analyzed with custom software (https://gitlab.com/DosenbachGreene/aloha/) that is publicly available, written in Python 3.6.[45] Using this algorithm, the mono-arm use index (MAUI) was calculated to describe how often children use their non-dominant upper limb in unilateral movements compared to their dominant upper limb over a 24 hour period.[27] The MAUI is the ratio of the summed magnitude of all independent movements of each arm. Since the upper limb movements are largely bilateral in nature, the MAUI is able to more accurately capture the extent of deficit by quantifying the effort of each arm and the frequency of independent movement in everyday activities (eg, opening a door, turning on a light switch). To visualize this information, histograms were generated for each participant reflecting the intensity and frequency of unilateral movements of each upper limb over a 24-hour period.

Results

Participants

A total of 11 children 5 to 15 years of age were included in this study (Table 1). All participants had a diagnosis of hemiplegic CP, classified as either GMFCS I or II. The majority survived a presumed perinatal stroke (n = 6) while the remainder had brain injury associated with arteriovenous malformation and non-accidental trauma. The extent of neurological damage varied widely (Figure 1).

Behavior and cognitive assessment

Raw scores on all assessments were compared to normative data and interpreted based on instruction in their respective assessment manuals. Based on our clinical evaluation of cognition, 2 children had scores indicative of intellectual disability (<70) and 2 had scores indicating below average intelligence on the KBIT. However, we identified that the majority of our cohort had average cognitive scores when different components of cognition were measured individually using the NIH toolbox (Table 2). Some components of the toolbox (eg, episodic memory, picture sequence task) were not completed by all children because of equipment malfunctioning.

Out of the 11 participants, 10 caregivers responded to the surveys. Scores were calculated and risk was interpreted based on directions in each assessment's respective manual. Three children (27%) had scores that indicated a high risk for developing a disorder of executive function (CPT). Based on scores from the CBCL, 3 children (27%) had scores suggestive of clinically significant internalizing behaviors and 2 (18%) of clinically significant externalizing behaviors. Four children (36%) had scores indicative of depression on the CDI.

Table 1. Characteristics of participants.

CHARACTERISTICS	N (%)	MEAN (SD)	RANGE
Child age, y	11	9.21 (3.07)	5.83-15.42
Sex			
Female	5 (45)		
Male	6 (55)		
Race			
White	10 (91)		
Asian	1 (9)		
Type of brain injury			
Perinatal stroke (presumed)	6 (55)		
AVM	1 (9)		
Anoxic brain injury	1 (9)		
Hemispherectomy	1 (9)		
Not reported/unknown	2 (18)		
Affected upper extremity			
Right	9 (82)		
Left	2 (18)		
GMFCS level			
I	8 (73)		
II	3 (27)		
Mother age, y	8	38.63 (5.53)	32-47
Family avg. yearly income ($)			
Less than 75 K	0		
75 000-100 000	5 (45)		
100 001-200 000	2 (18)		
More than 200 000	1 (9)		
Other/did not respond	3 (27)		

Neuroimaging outcomes

Overall, children tolerated MRI scanning well and were able to perform all test procedures. Out of the 11 children, we were able to obtain diagnostic images from 9 children. One child was considered too young (<6 years) to lie still in the scanner. Following the practice scan, 1 child refused to complete the scan and indicated she was scared. From the remaining scans, the injury presumed to be associated with deficits was identified for 8 children by an experienced neuroradiologist (JSS). Of interest, among this small cohort, the size of the injury varied substantially between individuals and did not correspond to level of behavioral or cognitive deficits.

Motor assessment

The Melbourne Assessment of Unilateral Upper Limb Function-2 (MA), tapping speed, grip, and pinch strength confirmed that the majority of participants experienced significant deficits in their non-dominant upper limb (Table 3). The scores from the MA indicate motor ability in each domain of the affected upper limb, where 100 would indicate typically developing with no deficit. Children demonstrated scores suggesting that tasks requiring fine motor dexterity were the most difficult to complete with their affected upper limb (eg, picking up a piece of cereal, rotating a cube). We observed that while all children had a diagnosis of hemiplegic CP, motors deficits were also present in their less affected upper limb in tapping speed, grip and pinch strength. Compared to previously published norms, tapping speed was slow in the affected hand, but the less affected hand also demonstrated tapping speeds below that of typically developing peers.[40] Similarly, grip strength was markedly lower in the affected hand and the nonaffected hand also demonstrated diminished strength compared to typically developing peers.[41] Pinch strength fell below expected norms in the affected hand, while the mean pinch strength for the less affected hand fell well within normal limits.[41]

Real-world movement (accelerometry). The average MAUI ratio of 0.18 (SD = 0.18) for our cohort indicated asymmetrical motor activity in the upper extremities during real world activity throughout the day. The ratio of unilateral movements between the upper limbs was notable, as typically developing children move both upper limbs equally, with a ratio of close to 1.0.[27,46] The histograms in Figure 2 highlight that all children had visibly reduced unilateral movements in their affected upper limb, corroborating the low scores observed on the MA2.

Discussion

The purpose of this study was to replicate previous reports of behavioral deficits among children with hemiplegic CP, and secondarily to describe a battery of assessments to measure motor skills and behavior in this population. In our assessment battery we utilized clinical evaluation, neuroimaging, parent report, and accelerometry data. Despite the small sample size, our findings corroborate previous reports that the daily challenges for children with CP and their families are broader than motor impairment alone.

Our study identified disparate scores between the NIH Toolbox cognitive tests and the KBIT, with more deficits being identified by the latter. We found that the majority of our cohort did not have significant cognitive deficits. Given the known barriers to traditional intelligence testing,[47] it appears that more comprehensive and targeted measures of cognition, such as those in the NIH Toolbox, might more accurately capture cognition in this pediatric population. However, our sample was recruited from those that had been simultaneously
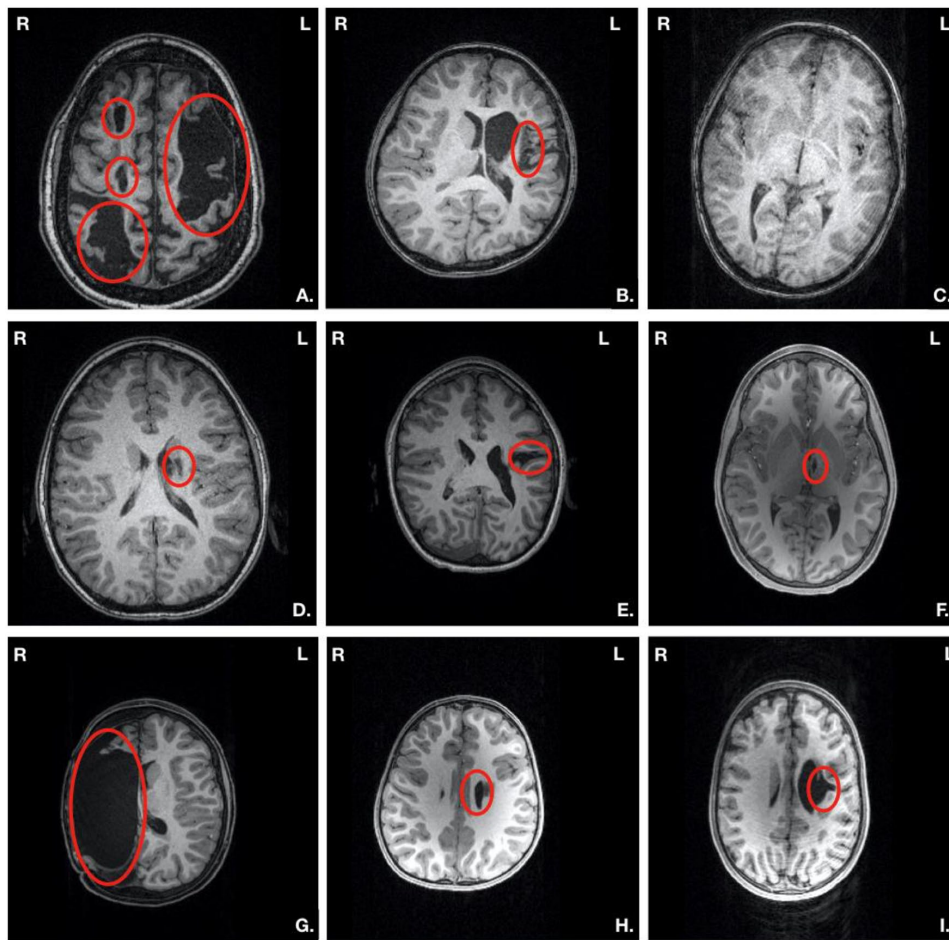
Figure 1. T1 Neuroimaging of children with varying severity of cerebral palsy.
Nine children had T1 scans and the injury was identified and is outlined in red (JSS). Based on medical history; Subject A, B, D, H had a perinatal stroke; Subject C had anoxic brain injury not visible on scan; Subject E and I did not know details of the injury but had an eligible diagnosis of CP. Subject F had an AVM. Subject G had shaken baby syndrome and associated epilepsy that required a hemispherectomy. Neuroimaging was not available for 2 participants (1 refused, 1 was <6 years).

Table 2. Cognition among children with cerebral palsy.

	N (%)	MEAN *(SD)*	RANGE
KBIT	11 (100)	79 *(41)*	0.1-127
Score 85+	7 (64)		
Score <85	4 (36)		
NIH toolbox: cognition			
Picture vocabulary	11 (100)	97.41 *(11.16)*	95-107
Inhibitory control	11 (100)	88.28 *(17.86)*	62-111
Working memory	10 (91)	94.70 *(19.93)*	48-116
Executive function	10 (91)	86.97 *(10.86)*	65-100
Processing speed	11 (100)	74.58 *(20.39)*	50-123
Episodic memory	7 (64)	102.61 *(21.46)*	67-135
Oral reading	10 (91)	85.21 *(15.87)*	64-118

KBIT=Kaufman Brief Intelligence Test.

Table 3. Motor capacity evaluation of children with cerebral palsy.

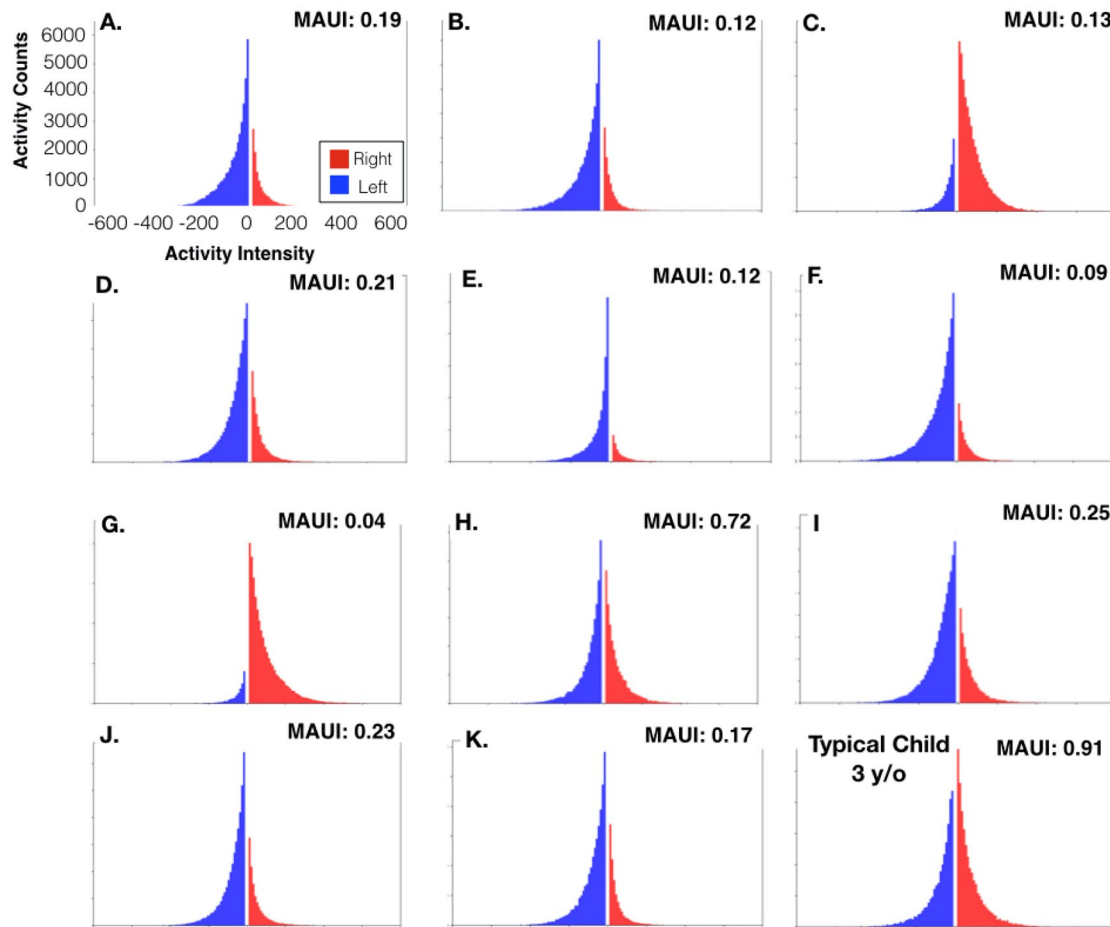|	MEAN *(SD)*	RANGE
MA2		
Range of motion	76.63 *(23.60)*	35-100
Accuracy	82.87 *(20.80)*	29-99
Dexterity	59.33 *(29.18)*	3-89
Fluency	75.66 *(19.68)*	50-100
Tap		
Affected UL	18.82 *(9.40)*	
Unaffected UL	39.48 *(13.03)*	
Grip		
Affected UL	12.15 *(11.15)*	
Unaffected UL	26.31 *(19.82)*	
Pinch		
Affected UL	6.30 *(4.02)*	
Unaffected UL	12.57 *(6.48)*	

UL=Upper Limb.

Figure 2. Histograms of unilateral upper limb movement for each participant.
Each histogram represents the unilateral movements of both upper limbs over the course of 24 hours with the ratio in the upper right corner. A lower ratio indicates a greater degree of difference between the upper limbs. The peak indicates the highest frequency of movement at each level of intensity based on magnitude of movement, such that smaller, lower acceleration movements are toward the center and larger movement toward the outer bounds of the *x*-axis.

selected for later intensive intervention and it is possible that our cohort experienced fewer cognitive impairments than other children with CP.

Behavioral characteristics must be considered when evaluating and treating CP, especially in regard to attention and depression, both of which can affect academic performance.[48,49] Over a quarter of our cohort had CDI scores indicating a risk of developing childhood depression. Including this psychosocial component in the assessment and treatment of CP may facilitate targeted intervention and improve long-term outcomes. However, further research is needed to understand which emotional and behavioral disorders are most prevalent among children with CP.

A unique component of this study was that we were able to use neuroimaging to visually identify the brain injuries associated with the children's hemiplegic motor impairments. We found that some children had extensive bilateral brain lesions, while others appeared much smaller, yet all of these children presented with hemiplegia. The findings from this study indicate that brain injury size may not necessarily correspond with the level of deficit experienced by the individual

(eg, Participant C did not have identifiable injury in Figure 1, yet there was a clear asymmetry in upper limb use, as seen in Figure 2). These findings correspond to previous research that identified that lesion size alone does not predict motor or functional outcomes associated with hemiplegia.[50] Future studies are needed to further investigate the relationship between lesion location and size and subsequent motor impairment experienced by the child in order to provide targeted therapeutic interventions.

Our cohort's scores on measures of motor capacity demonstrated significant impairment in the limbs affected by hemiplegia. Mean participant scores on the MA describe deficits in range of motion, accuracy, dexterity, and fluency, suggesting that tasks requiring fine motor dexterity were the most difficult to complete with their affected upper limb (eg, picking up a cheerio, rotating a cube). Unsurprisingly, tapping speed, grip strength, and pinch strength were markedly low in participants' affected limbs. However, we were surprised to find reduced tapping speeds and grip strength in participants' less affected limbs. Compared to previously published tapping speed norms, the less affected hand tapped at speeds below

those of typically developing peers.[40] Similarly, participants demonstrated diminished grip strength in their less affected hand compared to typically developing peers.[41] Mean pinch strength for the less affected hand fell well within normal limits.[41] While measurement of these variables can be difficult with children due to limited motivation or understanding of the task, we believe that the results obtained by our trained staff are valid and indicate a need for improved measurement of bilateral motor skills.

To better understand how children use their limbs throughout an average day, our participants wore accelerometer bracelets on each wrist for 25 hours. Screening tools such as accelerometers are an efficient and cost-effective way to identify children who are at the greatest risk for motor deficits, and consequently a CP diagnosis.[27] We found that these minimally invasive devices were well tolerated by children of all ages. The accelerometry data required little time to collect and analyze and allowed for an objective measurement of real-world upper limb activity. Corroborating previous reports, our data demonstrated that children with unilateral motor deficits documented in clinical evaluation also had lower activity in their affected upper limb.[51]

Despite a small sample size, which is a limitation of this study, we believe that these study results corroborate previous reports of behavioral deficits affecting children with hemiplegic CP. While our cohort represented individuals from an upper socio-economic class, we believe that these findings suggest that the non-motor sequelae of CP may be experienced by the broader CP population. Additionally, the brain injuries identified within our cohort varied in size and etiology, yet all children presented with the same diagnosis of hemiplegic CP. Future studies are needed to further explore these relationships and applicability to a broader population.

Conclusions

In conclusion, CP is a common condition affecting childhood development, yet it is often primarily described solely based on motor deficits. We found that implementing a comprehensive battery of assessments was achievable with this population by utilizing technology to support the collection of caregiver report measures and wearable devices to record real-world movement. Additionally, we report that with the exception of processing speed, cognition was average in this cohort. It is critical that future research and clinical evaluation should include screeners for depression and attention so that appropriate interventions are provided to maximize the child's ability to succeed.

Author Contributions

CRH contributed to the study design, data collection, analysis, interpretation and major manuscript preparation. SS interpreted the data and was a major contributor in writing the manuscript. SB was a major contributor in data collection, analysis and interpretation. DJN, ANV, RLM, JSS, MO contributed to data analysis and interpretation. ANV contributed to study design and data collection. BLS made substantial contributions to the study design and interpretation of the data. NUFD contributed to the study design, data collection, analysis and interpretation and was a substantial contributor to manuscript preparation. All authors read and approved the final manuscript.

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