Feasibility of using accelerometer data to quantify real-world bimanual performance and compare to in-clinic hand capacity measures in children with unilateral cerebral palsy

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A Signature Honors Project Presented to the

Honors College

East Carolina University

In Partial Fulfillment of the

Requirements for

Graduation with Honors

by

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May 2023

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Introduction

Cerebral Palsy (CP) is a leading cause of childhood disability (Novak et al., 2017). Children with CP present with neuromuscular impairments that limit the child's mobility and restrict participation in educational, leisure, and vocational roles (CDC, 2021). The severity of CP can vary widely, with some individuals having only minor motor impairments, while others may have significant disabilities that impact their daily life (CDC, 2021). Unilateral cerebral palsy (UCP) is a type of cerebral palsy that affects one side of the body, typically the arm and leg. In developed countries, CP affects 2 to 2.5 per 1000 live births (Odding et al., 2006). Approximately 30% of all cases of CP are classified as UCP (Himmelmann et al., 2010). Rehabilitation is the only few options to improve function, reduce disability, promote independence, and improve overall quality of life in children with UCP. Little is known about which interventions are the most effective in improving hand function in children with UCP (Novak, 2014). However, intensive upper limb therapies, like Hand-Arm Bimanual Intensive Training (HABIT), have been found to be effective in promoting bimanual performance and daily functioning (Novak, 2014).

The World Health Organization divides ability to execute a task into functional capacity vs. performance (WHO, 2002). Primary outcomes in CP rehabilitation are measured at the functional capacity level, where capacity is defined as what a person is capable of doing in the structured environment of the clinic or laboratory. It has long been assumed that improvements in capacity result in improvements in performance, where performance is defined as what a person actually does in daily life, outside of the clinic or laboratory. Traditionally, studies examining the efficacy of HABIT have assessed changes in upper extremity (UE) capacity using standardized clinical tests such as Box and Block Test (BBT), Nine-Hole Peg Test (NHPT), Jebsen Hand Function Test (JHFT) etc (Ouyang et al., 2020). Whereas UE performance has been assessed using self-reported measures such as Canadian Occupational Performance Measure, Pediatric Evaluation and Disability Inventory, and ABILHAND (Ouyang et al., 2020). These studies indicate that HABIT improves UE capacity as well as performance of children with UCP. However, self-report measures are prone to subjective bias which questions whether in-clinic improvements are indicative of change in real-world bimanual activities (Scheithauer et al., 2022). There is currently a gap in the current literature as HABIT is marked by capacity measures and have not studied HABIT's effect on real world performance gains. It is known that accelerometry based measures can objectively quantify the performance of activities of daily living making. (Hoyt et al., 2020). This objective measure of performance has not been explored with HABIT making this a need to assess whether HABIT improves performance using objective accelerometer derived data.

In a study done with stroke survivors, new data is suggesting that upper limb capacity measures do not reflect upper limb performance in daily life (Waddell et al., 2017). Current evidence in individuals with neurological conditions such Parkinson's disease and CP also suggest that capacity does not always correlate with performance (Maetzler et al., 2021). These accelerometer-based measures that assessed performance suggest that interventions may improve capacity but do not improve performance. However, such relationship has not been investigated in children with UCP. Assessing this relationship in children with UCP is crucial to understand the effects of rehabilitation intervention in terms of the construct of capacity and performance measures. Therefore, there is a need to assess whether capacity of a child with UCP correlates with performance and this could allow clinicians to design more effective interventions for children with CP.

The purpose of this study is to assess the correlation between the hand capacity measures such as Box and Block (BBT), Nine-Hole Peg Test (NHPT), Jebson's Hand Function Test (JHFT), and handheld dynamometer scores with performance measures such as accelerometry derived variables. And to determine the effects of Hand-Arm Bimanual Intensive Training (HABIT) on real world bimanual performance in children with Unilateral CP (UCP). It is predicted that upper limb capacity may have weak correlation with upper extremity performance in children with CP.

Methods

HABIT

HABIT in a camp-based setting including structured, task-specific, bimanual activities for 6 hours/ day for 5-days, totaling 30-hours. Each child was paired with one student physical therapist and 2-3 undergraduate volunteers. Under the supervision of licensed physical therapist, they developed the individualized plan of care to achieve the child's goals. To assess real-world bimanual performance, children wore GT9X Link accelerometers on both wrists for 3 days pre- and post-HABIT.

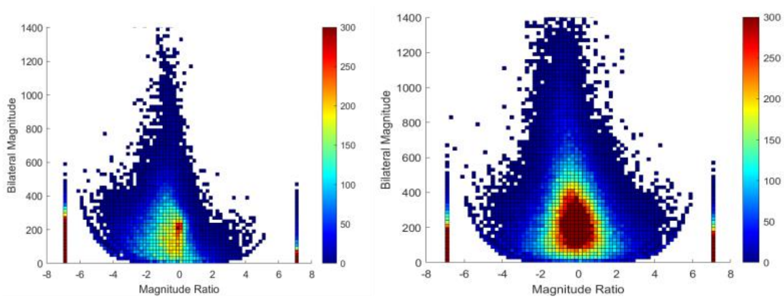
Figure 1: A participant working with volunteers on bimanual cup stacking during HABIT

Accelerometers

Real-world bimanual performance gains were quantified with through accelerometer derived variables– affected use count (number of movements), use ratio (UR), magnitude ratio (MR), bilateral magnitude (BM), median acceleration (MA), and acceleration variability (AV). UR and MR quantify the relative contribution of affected UE to bimanual tasks in terms of hours and magnitude. BM, MA, and AV quantify the magnitude of bilateral UE and affected UE movements.

Figure 2: Participant wearing accelerometers will coloring during HABIT

Coordination and hand function capacity were assessed using NHPT, JHFT, and BBT; and hand/pinch strength using dynamometers.



<u>Pre</u> **<u>Post</u>**

Figure 3: a representative example of a density plot, which illustrates accelerometer data obtained from both upper extremities.

<u>JHFT Protocol</u>

The Jebsen's Hand Function Test was designed to provide a short, objective test of hand function for activities of daily living. It has 7 items and takes approximately 15-45 minutes to administer. The 7 items included: writing, turning over 3-by-5 inch cards, picking up small common objects, simulated feeding, stacking checkers, picking up large light objects and picking up large heavy objects. The results are measured by timing the time taken to accomplish each task. The tests are always presented in the same order and are performed with the non-dominant hand first. Smaller amount of time to complete the task indicates better performance.

Figure 4: Example of JHFT equipment used to test overall hand function.

<u>BBT Protocol</u>

The BBT measures unilateral gross manual dexterity, and the administration consists of asking the child to move, one by one, the maximum number of blocks from one compartment of a box to another of equal size, within 60 seconds. If the child transferred 2 or more blocks at once this was counted as one block. The box should be oriented lengthwise and placed at the client's midline, with the compartment holding the blocks oriented towards the hand being tested. In order to practice and register baseline scores, the test should begin with the unaffected upper limb. Additionally, a 15-second trial period is permitted at the beginning of each side. Before the trial, after the standardized instructions are given to the children, they should be advised that their fingertips must cross the partition when transferring the blocks, and that they do not need to pick up the blocks that might fall outside of the box. Greater number of blocks transferred indicate better manual dexterity.

Figure 5: An example of the BBT used to measure unilateral gross manual dexterity.

NHPT Protocol

The NHPT was used to measure finger dexterity. For this test a plastic board with 9 holes with a shallow round dish at the end of the board was used. The children were instructed to take the pegs from the dish, one by one, and place them into the holes on the board, as quickly as possible, using only the hand being evaluated. Then, the child was instructed to remove the pegs from the holes, one by one, and replace them back into the dish. An evaluator started the stopwatch as soon as the child touched the first peg and was stopped once the last peg was back in the dish. Scoring is how long it took the child to complete this task. Smaller amount of time to complete the task indicates better performance.

Figure 6: Example of NHPT used to measure finger dexterity.

Hand & Pinch Strength

A hand dynamometer was used to assess hand strength. The children were seated with their feet flat on the floor with their elbow on the table. The children were instructed to squeeze as possible and to hold it for 3 seconds. The highest tick was recorded for the 2 trials done on both unaffected and affected hands. The same process was repeated using a finger dynamometer to assess pinch strength.

Figure 7: An example of the dynamometer used to test hand strength.

Figure 8: An example of the pinch dynamometer used to test pinch strength.

<u>Results</u>

<u>Participants</u>

This was a cross sectional study that included 24 children with UCP (age: 10.88±3.55 years; M=18, F=6) and MACS levels I-III. Children were between the ages of 6 and 16 years of age and were recruited from cities across North Carolina, Tennessee, and Virginia and two children flew in from Mexico. Children were excluded if they were prone to seizures and/or were diagnosed with a cognitive disability, communication issues, Botox in UE in the last 6-months, metabolic disorders. There were 14 children whose UCP affected their right upper extremity and there were 10 children with an affected left upper extremity. All children included in this study had 72 hours of accelerometer data for both pre- and post- HABIT. Demographic data is outlined in Table 1.

Table. 1: Demographics

Demographics of Participants		
Children		N
Age, yrs. (mean, range)		10.88, (6-16)
Sex		
	Male	18
	Female	6
Affected Limb		
	Right	14
	Left	10

Pre- and Post- HABIT Capacity

For each participant, JHFT, NHPT, BBT, and grip/pinch strength were all tested pre- and -post HABIT to explore the effect HABIT has on capacity. There was found to be a 14.4% increase in the number of blocks transferred in BBT. There was a 14.2% decrease in the time for participants to complete the JHFT. NHPT only saw a 0.89% decrease in time of completion. There was a 21.1% decrease in hand strength but a 26.7% increase in pinch strength. Differences were calculated to measure the average change in capacity for each test as seen in Table 2.

Table 2: Capacity Test Data

	BBT		JHFT		NHPT		Hand Strength		Pinch Strength	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Average	18.42	21.08	267.32	234.12	121.16	120.09	13.78	11.38	4.65	5.89
Standard Dev	7.24	8.17	125.25	114.13	35.48	43.29	10.93	10.92	4.05	4.20

A Paired t-test was run on each pre- and post- capacity measure to determine whether there is statistical evidence that the mean difference between paired observations is significantly different from zero. Significant figures ($p < 0.05$) in capacity measures were found which includes the BBT, JHFT, and NHPT as seen in Tables 3-5. The non-significant figures ($p > 0.05$) include hand strength and pinch strength as seen in Tables 6-7.

Table 3: BBT Paired T-test Results

BBT Paired T-Test		
	Pre	*Post*
Mean	20.7083333	23.4583333
Variance	86.5634058	88.5199275
Observations	24	24
Pearson Corre	0.9358654	
Hypothesized	0	
df	23	
t Stat	-4.0185739	
P(T<=t) one-ta	0.00026859	
t Critical one-t	1.71387153	
P(T<=t) two-ta	0.00053718	
t Critical two-	2.06865761	

Table 4: JHFT Paired T-test Results

JHFT t-Test: Paired Two Sample for Means		
	Pre	*Post*
Mean	271.624167	213.969167
Variance	19191.6017	10889.5847
Observations	24	24
Pearson Corre	0.80321469	
Hypothesized	0	
df	23	
t Stat	3.41071725	
P(T<=t) one-ta	0.00119774	
t Critical one-t	1.71387153	
P(T<=t) two-ta	0.00239548	
t Critical two-	2.06865761	

Table 5: NHPT Paired T-test Results

NHPT t-Test: Paired Two Sample for Means		
	Pre	*Post*
Mean	140.839762	115.977381
Variance	2956.38994	1774.72208
Observations	21	21
Pearson Corre	0.60904803	
Hypothesized	0	
df	20	
t Stat	2.58609135	
P(T<=t) one-ta	0.00882478	
t Critical one-	1.72471824	
P(T<=t) two-ta	0.01764956	
t Critical two-	2.08596345	

Table 6: Hand Strength Paired T-test Results

Hand Strength t-Test: Paired Two Sample for Means		
	Pre	*Post*
Mean	15.006087	17.2608696
Variance	159.292061	231.269763
Observations	23	23
Pearson Corre	0.8766838	
Hypothesized	0	
df	22	
t Stat	-1.4711654	
P(T<=t) one-ta	0.07770323	
t Critical one-	1.71714437	
P(T<=t) two-ta	0.15540647	
t Critical two-	2.07387307	

Table 7: Pinch Strength Paired T-test Results

Pinch Strength t-Test: Paired Two Sample for Means		
	Pre	*Post*
Mean	4.14326087	7.72130435
Variance	11.1245855	188.577603
Observations	23	23
Pearson Corre	0.41421928	
Hypothesized	0	
df	22	
t Stat	-1.3492017	
P(T<=t) one-ta	0.09549767	
t Critical one-t	1.71714437	
P(T<=t) two-ta	0.19099534	
t Critical two-t	2.07387307	

Pre- and Post- HABIT Performance

Each participant wore accelerometers for 3 consecutive days pre- and post- HABIT and the accelerometer derived variables were compared pre- to post- HABIT. Based on the averages, there was a 5.4% increase in UR, 50.5% increase in MR, 12.3% increase in BM, 32.1% increase in MA, and 8.4% increase in AV. Differences were calculated to measure the average change in performance for each test as seen in Table 3.

Table 8: Accelerometer Derived Performance Data

	Use Ratio		Magnitude Ratio		Bilateral Magnitude		Median Acceleration		Acceleration Variability	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Average	0.74	0.78	-1.58	-1.05	105.20	118.13	22.59	29.85	71.04	76.98
Standard Dev	0.12	0.11	1.57	0.60	29.04	24.85	15.23	17.83	15.75	16.67

A Paired t-test was run on each Pre- and Post- accelerometer derived variable to determine whether there is statistical evidence that the mean difference between paired observations is significantly different from zero. Significant figures ($p < 0.05$) include UR, BM, MA, and AV as seen in Tables 9, 11-13. MR is determined to be a non-significant ($p > 0.05$) figure as seen in Table 10.

Table 9: Use Ratio Paired T-test Results

UR t-Test: Paired Two Sample for Means		
	Pre	*Post*
Mean	0.7398847	0.77921891
Variance	0.01415692	0.01315886
Observations	24	24
Pearson Corre	0.86564638	
Hypothesized	0	
df	23	
t Stat	-3.1740394	
P(T<=t) one-ta	0.00211651	
t Critical one-t	1.71387153	
P(T<=t) two-ta	0.00423301	
t Critical two-	2.06865761	

Table 10: Magnitude Ratio Paired T-test Results

MR t-Test: Paired Two Sample for Means		
	Pre	*Post*
Mean	-1.5831876	-1.0491595
Variance	2.45041189	0.36516565
Observations	24	24
Pearson Corre	0.56001472	
Hypothesized	0	
df	23	
t Stat	-1.9742212	
P(T<=t) one-ta	0.03024205	
t Critical one-t	1.71387153	
P(T<=t) two-ta	0.06048411	
t Critical two-	2.06865761	

Table 11: Bilateral Magnitude Paired T-test Results

BM t-Test: Paired Two Sample for Means		
	Pre	*Post*
Mean	105.20084	118.127818
Variance	843.119307	617.599597
Observations	24	24
Pearson Corre	0.71752417	
Hypothesized	0	
df	23	
t Stat	-3.0712411	
P(T<=t) one-ta	0.00270154	
t Critical one-t	1.71387153	
P(T<=t) two-ta	0.00540308	
t Critical two-	2.06865761	

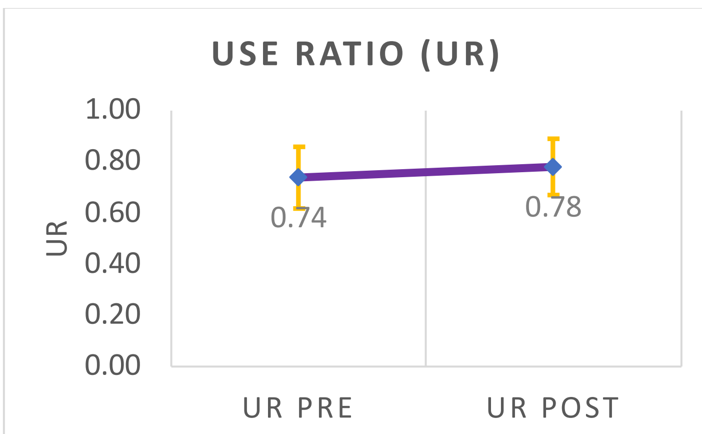
Table 12: Median Acceleration Paired T-test Results

MA t-Test: Paired Two Sample for Means		
	Pre	*Post*
Mean	22.594111	29.8466402
Variance	232.093374	318.077103
Observations	24	24
Pearson Corre	0.84027099	
Hypothesized	0	
df	23	
t Stat	-3.6732679	
P(T<=t) one-ta	0.00063078	
t Critical one-t	1.71387153	
P(T<=t) two-ta	0.00126156	
t Critical two-	2.06865761	

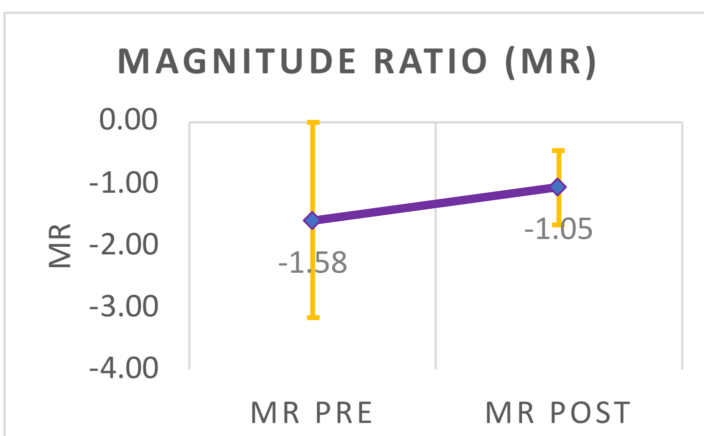
Table 13: Acceleration Variability Paired T-test Results

AV t-Test: Paired Two Sample for Means		
	Pre	*Post*
Mean	71.0417645	76.9834913
Variance	248.058319	277.966361
Observations	24	24
Pearson Corre	0.76641129	
Hypothesized	0	
df	23	
t Stat	-2.6190262	
P(T<=t) one-ta	0.00767072	
t Critical one-t	1.71387153	
P(T<=t) two-ta	0.01534144	
t Critical two-t	2.06865761	

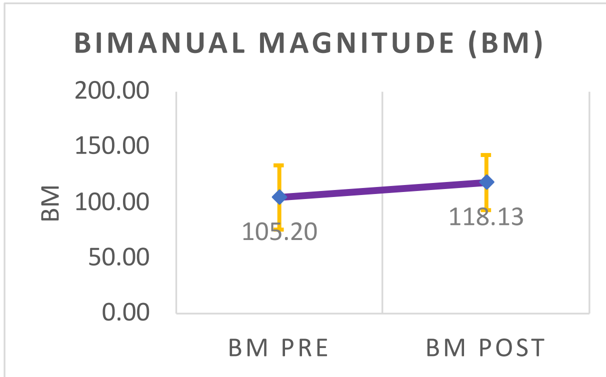
Graph 1: Use Ratio Pre- and Post- HABIT



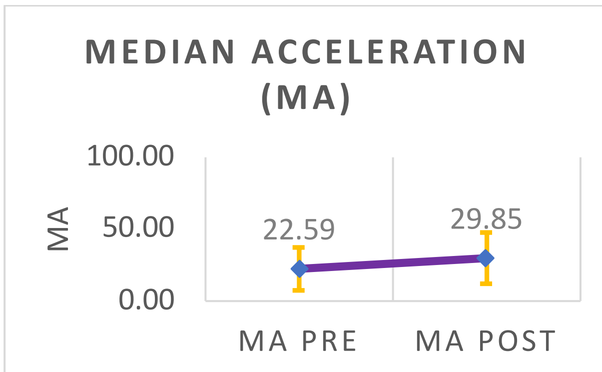
Graph 2: Magnitude Ratio Pre- and Post- HABIT



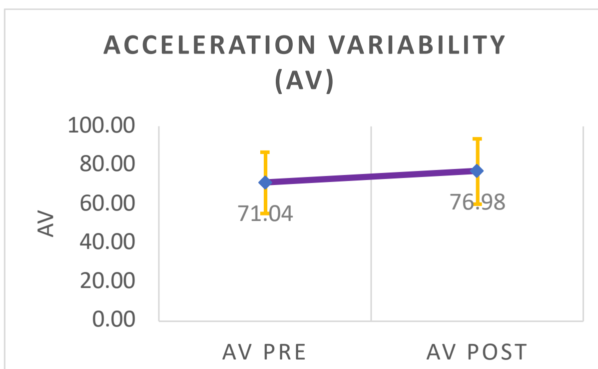
Graph 3: Bimanual Magnitude Pre- and Post- HABIT



Graph 4: Median Acceleration Pre- and Post- HABIT



Graph 5: Acceleration Variability Pre- and Post- HABIT



<u>Capacity vs Performance</u>

All data was quantitative, and to explore the correlation between the capacity and performance, a correlation analysis was performed using Pearson's correlation test between the difference in pre- and -post HABIT of each accelerometry measure and upper extremity capacity measures. There were significant improvements in both capacity measures and performance measures. Overall, there was a very weak correlation ($-0.19 \leq r \leq 0.19$) between capacity measures and accelerometer derived performance measures as marked as red in Tables 11-15. Pearson's Correlation Coefficient (r.) is color coded to illustrate the strength of correlation. ($-0.19 \leq r \leq 0.19$) represents a very weak correlation, ($\pm0.20 \leq r \leq \pm0.39$) is a weak correlation, ($\pm0.40 \leq r \leq \pm0.59$) is a moderate correlation, ($\pm0.60 \leq r \leq \pm0.79$) is a strong correlation, and ($\pm0.80 \leq r \leq \pm1.0$) is a strong correlation as seen in Table 10. There was a negative weak correlation ($r \leq -0.2 – -0.39$) found in NHPT vs UR, MR and MA as seen in Table 13 and Graphs 9-11. There was a positive weak correlation ($0.2 \leq r \leq 0.39$) found in Hand-Strength vs UR, MA, and AV as seen in Table 14 and Graphs 6-8.

Table 10: Correlation Scale

Correlation Key "r"	
Strength of Correlat	Range +/-
very strong	0.8-1
strong	0.6-0.79
moderate	0.4-0.59
weak	0.2-0.39
very weak	0-0.19

Table 11: BBT vs Accelerometer Derived Variables

Descriptive Statistics

	Mean	Std. Deviation	N
URDiff	0.0392	0.061	24
BBTDiff	2.75	3.35248	24

Correlations

		URDiff	BBTDiff
URDiff	Pearson Correlation	1	0.082
	Sig. (2-tailed)		0.704
	N	24	24
BBTDiff	Pearson Correlation	0.082	1
	Sig. (2-tailed)	0.704	
	N	24	24

Confidence Intervals

	Pearson Correlation	Sig. (2-tailed)	95% Confidence Intervals (2-tailed)[a] Lower	Upper
URDiff - BBTDiff	0.082	0.704	-0.333	0.47

a. Estimation is based on Fisher's r-to-z transformation.

Descriptive Statistics

	Mean	Std. Deviation	N
BBTDiff	2.75	3.35248	24
MRDiff	0.5333	1.32513	24

Correlations

		BBTDiff	MRDiff
BBTDiff	Pearson Correlation	1	0.173
	Sig. (2-tailed)		0.418
	N	24	24
MRDiff	Pearson Correlation	0.173	1
	Sig. (2-tailed)	0.418	
	N	24	24

Confidence Intervals

	Pearson Correlation	Sig. (2-tailed)	95% Confidence Intervals (2-tailed)[a] Lower	Upper
BBTDiff - MRDiff	0.173	0.418	-0.247	0.539

a. Estimation is based on Fisher's r-to-z transformation.

Descriptive Statistics

	Mean	Std. Deviation	N
BBTDiff	2.75	3.35248	24
BMDiff	12.9263	20.62015	24

Correlations

		BBTDiff	BMDiff
BBTDiff	Pearson Correlation	1	0.156
	Sig. (2-tailed)		0.466
	N	24	24
BMDiff	Pearson Correlation	0.156	1
	Sig. (2-tailed)	0.466	
	N	24	24

Confidence Intervals

	Pearson Correlation	Sig. (2-tailed)	95% Confidence Intervals (2-tailed)[a] Lower	Upper
BBTDiff - BMDiff	0.156	0.466	-0.264	0.526

a. Estimation is based on Fisher's r-to-z transformation.

Descriptive Statistics

	Mean	Std. Deviation	N
BBTDiff	2.75	3.35248	24
MADiff	7.2521	9.67231	24

Correlations

		BBTDiff	MADiff
BBTDiff	Pearson Correlation	1	0.134
	Sig. (2-tailed)		0.533
	N	24	24
MADiff	Pearson Correlation	0.134	1
	Sig. (2-tailed)	0.533	
	N	24	24

Confidence Intervals

	Pearson Correlation	Sig. (2-tailed)	95% Confidence Intervals (2-tailed)[a] Lower	Upper
BBTDiff - MADiff	0.134	0.533	-0.285	0.51

a. Estimation is based on Fisher's r-to-z transformation.

Descriptive Statistics

	Mean	Std. Deviation	N
BBTDiff	2.75	3.35248	24
AVDiff	5.9408	11.11436	24

Correlations

		BBTDiff	AVDiff
BBTDiff	Pearson Correlation	1	0.134
	Sig. (2-tailed)		0.532
	N	24	24
AVDiff	Pearson Correlation	0.134	1
	Sig. (2-tailed)	0.532	
	N	24	24

Confidence Intervals

	Pearson Correlation	Sig. (2-tailed)	95% Confidence Intervals (2-tailed)[a] Lower	Upper
BBTDiff - AVDiff	0.134	0.532	-0.285	0.51

a. Estimation is based on Fisher's r-to-z transformation.

Table 12: JHFT vs Accelerometer Derived Variables

Descriptive Statistics

	Mean	Std. Deviation	N
URDiff	0.0392	0.061	24
JHFTDiff	-57.655	82.81269	24

Correlations

		URDiff	JHFTDiff
URDiff	Pearson Correlation	1	0.163
	Sig. (2-tailed)		0.448
	N	24	24
JHFTDiff	Pearson Correlation	0.163	1
	Sig. (2-tailed)	0.448	
	N	24	24

Confidence Intervals

	Pearson Correlation	Sig. (2-tailed)	95% Confidence Intervals (2-tailed)[a] Lower	Upper
URDiff - JHFTDiff	0.163	0.448	-0.258	0.531

a. Estimation is based on Fisher's r-to-z transformation.

Descriptive Statistics

	Mean	Std. Deviation	N
JHFTDiff	-57.655	82.81269	24
MRDiff	0.5333	1.32513	24

Correlations

		JHFTDiff	MRDiff
JHFTDiff	Pearson Correlation	1	0.053
	Sig. (2-tailed)		0.807
	N	24	24
MRDiff	Pearson Correlation	0.053	1
	Sig. (2-tailed)	0.807	
	N	24	24

Confidence Intervals

	Pearson Correlation	Sig. (2-tailed)	95% Confidence Intervals (2-tailed)[a] Lower	Upper
JHFTDiff - MRDiff	0.053	0.807	-0.358	0.446

a. Estimation is based on Fisher's r-to-z transformation.

Descriptive Statistics

	Mean	Std. Deviation	N
JHFTDiff	-57.655	82.81269	24
BMDiff	12.9263	20.62015	24

Correlations

		JHFTDiff	BMDiff
JHFTDiff	Pearson Correlation	1	0.186
	Sig. (2-tailed)		0.385
	N	24	24
BMDiff	Pearson Correlation	0.186	1
	Sig. (2-tailed)	0.385	
	N	24	24

Confidence Intervals

	Pearson Correlation	Sig. (2-tailed)	95% Confidence Intervals (2-tailed)[a] Lower	Upper
JHFTDiff - BMDiff	0.186	0.385	-0.235	0.548

a. Estimation is based on Fisher's r-to-z transformation.

Correlations

Notes

Descriptive Statistics

	Mean	Std. Deviation	N
JHFTDiff	-57.655	82.81269	24
MADiff	7.2521	9.67231	24

Correlations

		JHFTDiff	MADiff
JHFTDiff	Pearson Correlation	1	0.148
	Sig. (2-tailed)		0.49
	N	24	24
MADiff	Pearson Correlation	0.148	1
	Sig. (2-tailed)	0.49	
	N	24	24

Confidence Intervals

	Pearson Correlation	Sig. (2-tailed)	95% Confidence Intervals (2-tailed)[a] Lower	Upper
JHFTDiff - MADiff	0.148	0.49	-0.271	0.52

a. Estimation is based on Fisher's r-to-z transformation.

Descriptive Statistics

	Mean	Std. Deviation	N
JHFTDiff	-57.655	82.81269	24
AVDiff	5.9408	11.11436	24

Correlations

		JHFTDiff	AVDiff
JHFTDiff	Pearson Correlation	1	-0.087
	Sig. (2-tailed)		0.687
	N	24	24
AVDiff	Pearson Correlation	-0.087	1
	Sig. (2-tailed)	0.687	
	N	24	24

Confidence Intervals

	Pearson Correlation	Sig. (2-tailed)	95% Confidence Intervals (2-tailed)[a] Lower	Upper
JHFTDiff - AVDiff	-0.087	0.687	-0.473	0.328

a. Estimation is based on Fisher's r-to-z transformation.

Table 13: NHPT vs Accelerometer Derived Variables

Descriptive Statistics

	Mean	Std. Deviation	N
NHPTDiff	-27.2491	42.82416	23
URDiff	0.0392	0.061	24

Correlations

		NHPTDiff	URDiff
NHPTDiff	Pearson Correlation	1	-0.379
	Sig. (2-tailed)		0.075
	N	23	23
URDiff	Pearson Correlation	-0.379	1
	Sig. (2-tailed)	0.075	
	N	23	24

Confidence Intervals

	Pearson Correlation	Sig. (2-tailed)	95% Confidence Intervals (2-tailed)[a] Lower	Upper
NHPTDiff - URDiff	-0.379	0.075	-0.684	0.039

a. Estimation is based on Fisher's r-to-z transformation.

Descriptive Statistics

	Mean	Std. Deviation	N
NHPTDiff	-27.2491	42.82416	23
MRDiff	0.5333	1.32513	24

Correlations

		NHPTDiff	MRDiff
NHPTDiff	Pearson Correlation	1	-0.266
	Sig. (2-tailed)		0.22
	N	23	23
MRDiff	Pearson Correlation	-0.266	1
	Sig. (2-tailed)	0.22	
	N	23	24

Confidence Intervals

	Pearson Correlation	Sig. (2-tailed)	95% Confidence Intervals (2-tailed)[a] Lower	Upper
NHPTDiff - MRDiff	-0.266	0.22	-0.611	0.164

a. Estimation is based on Fisher's r-to-z transformation.

Descriptive Statistics

	Mean	Std. Deviation	N
NHPTDiff	-27.2491	42.82416	23
BMDiff	12.9263	20.62015	24

Correlations

		NHPTDiff	BMDiff
NHPTDiff	Pearson Correlation	1	-0.079
	Sig. (2-tailed)		0.721
	N	23	23
BMDiff	Pearson Correlation	-0.079	1
	Sig. (2-tailed)	0.721	
	N	23	24

Confidence Intervals

	Pearson Correlation	Sig. (2-tailed)	95% Confidence Intervals (2-tailed)[a] Lower	Upper
NHPTDiff - BMDiff	-0.079	0.721	-0.476	0.345

a. Estimation is based on Fisher's r-to-z transformation.

Correlations

Notes

Descriptive Statistics

	Mean	Std. Deviation	N
NHPTDiff	-27.2491	42.82416	23
MADiff	7.2521	9.67231	24

Correlations

		NHPTDiff	MADiff
NHPTDiff	Pearson Correlation	1	-0.211
	Sig. (2-tailed)		0.335
	N	23	23
MADiff	Pearson Correlation	-0.211	1
	Sig. (2-tailed)	0.335	
	N	23	24

Confidence Intervals

	Pearson Correlation	Sig. (2-tailed)	95% Confidence Intervals (2-tailed)[a] Lower	Upper
NHPTDiff - MADiff	-0.211	0.335	-0.573	0.221

a. Estimation is based on Fisher's r-to-z transformation.

Descriptive Statistics

	Mean	Std. Deviation	N
NHPTDiff	-27.2491	42.82416	23
AVDiff	5.9408	11.11436	24

Correlations

		NHPTDiff	AVDiff
NHPTDiff	Pearson Correlation	1	-0.188
	Sig. (2-tailed)		0.391
	N	23	23
AVDiff	Pearson Correlation	-0.188	1
	Sig. (2-tailed)	0.391	
	N	23	24

Confidence Intervals

	Pearson Correlation	Sig. (2-tailed)	95% Confidence Intervals (2-tailed)[a] Lower	Upper
NHPTDiff - AVDiff	-0.188	0.391	-0.557	0.243

Table 14: Hand Strength vs Accelerometer Derived Variables

Descriptive Statistics

	Mean	Std. Deviation	N
HandDiff	2.8413	7.74164	24
URDiff	0.0392	0.061	24

Correlations

		HandDiff	URDiff
HandDiff	Pearson Correlation	1	0.229
	Sig. (2-tailed)		0.281
	N	24	24
URDiff	Pearson Correlation	0.229	1
	Sig. (2-tailed)	0.281	
	N	24	24

Confidence Intervals

	Pearson Correlation	Sig. (2-tailed)	95% Confidence Intervals (2-tailed)[a] Lower	Upper
HandDiff - URDiff	0.229	0.281	-0.192	0.579

a. Estimation is based on Fisher's r-to-z transformation.

Descriptive Statistics

	Mean	Std. Deviation	N
HandDiff	2.8413	7.74164	24
MRDiff	0.5333	1.32513	24

Correlations

		HandDiff	MRDiff
HandDiff	Pearson Correlation	1	0.044
	Sig. (2-tailed)		0.837
	N	24	24
MRDiff	Pearson Correlation	0.044	1
	Sig. (2-tailed)	0.837	
	N	24	24

Confidence Intervals

	Pearson Correlation	Sig. (2-tailed)	95% Confidence Intervals (2-tailed)[a] Lower	Upper
HandDiff - MRDiff	0.044	0.837	-0.366	0.44

a. Estimation is based on Fisher's r-to-z transformation.

Descriptive Statistics

	Mean	Std. Deviation	N
HandDiff	2.8413	7.74164	24
BMDiff	12.9263	20.62015	24

Correlations

		HandDiff	BMDiff
HandDiff	Pearson Correlation	1	-0.001
	Sig. (2-tailed)		0.998
	N	24	24
BMDiff	Pearson Correlation	-0.001	1
	Sig. (2-tailed)	0.998	
	N	24	24

Confidence Intervals

	Pearson Correlation	Sig. (2-tailed)	95% Confidence Intervals (2-tailed)[a] Lower	Upper
HandDiff - BMDiff	-0.001	0.998	-0.404	0.403

a. Estimation is based on Fisher's r-to-z transformation.

Correlations

Notes

Descriptive Statistics

	Mean	Std. Deviation	N
HandDiff	2.8413	7.74164	24
MADiff	7.2521	9.67231	24

Correlations

		HandDiff	MADiff
HandDiff	Pearson Correlation	1	0.203
	Sig. (2-tailed)		0.342
	N	24	24
MADiff	Pearson Correlation	0.203	1
	Sig. (2-tailed)	0.342	
	N	24	24

Confidence Intervals

	Pearson Correlation	Sig. (2-tailed)	95% Confidence Intervals (2-tailed)[a] Lower	Upper
HandDiff - MADiff	0.203	0.342	-0.218	0.56

a. Estimation is based on Fisher's r-to-z transformation.

Descriptive Statistics

	Mean	Std. Deviation	N
HandDiff	2.8413	7.74164	24
AVDiff	5.9408	11.11436	24

Correlations

		HandDiff	AVDiff
HandDiff	Pearson Correlation	1	0.348
	Sig. (2-tailed)		0.096
	N	24	24
AVDiff	Pearson Correlation	0.348	1
	Sig. (2-tailed)	0.096	
	N	24	24

Confidence Intervals

	Pearson Correlation	Sig. (2-tailed)	95% Confidence Intervals (2-tailed)[a] Lower	Upper
HandDiff - AVDiff	0.348	0.096	-0.064	0.659

a. Estimation is based on Fisher's r-to-z transformation.

Table 15: Pinch Strength vs Accelerometer Derived Variables

Descriptive Statistics

	Mean	Std. Deviation	N
PinchDiff	3.3873	12.4739	24
URDiff	0.0392	0.061	24

Correlations

		PinchDiff	URDiff
PinchDiff	Pearson Correlation	1	0.063
	Sig. (2-tailed)		0.769
	N	24	24
URDiff	Pearson Correlation	0.063	1
	Sig. (2-tailed)	0.769	
	N	24	24

Confidence Intervals

	Pearson Correlation	Sig. (2-tailed)	95% Confidence Intervals (2-tailed)[a] Lower	Upper
PinchDiff - URDiff	0.063	0.769	-0.349	0.455

a. Estimation is based on Fisher's r-to-z transformation.

Descriptive Statistics

	Mean	Std. Deviation	N
PinchDiff	3.3873	12.4739	24
MRDiff	0.5333	1.32513	24

Correlations

		PinchDiff	MRDiff
PinchDiff	Pearson Correlation	1	-0.055
	Sig. (2-tailed)		0.797
	N	24	24
MRDiff	Pearson Correlation	-0.055	1
	Sig. (2-tailed)	0.797	
	N	24	24

Confidence Intervals

	Pearson Correlation	Sig. (2-tailed)	95% Confidence Intervals (2-tailed)[a] Lower	Upper
PinchDiff - MRDiff	-0.055	0.797	-0.449	0.356

a. Estimation is based on Fisher's r-to-z transformation.

Descriptive Statistics

	Mean	Std. Deviation	N
PinchDiff	3.3873	12.4739	24
BMDiff	12.9263	20.62015	24

Correlations

		PinchDiff	BMDiff
PinchDiff	Pearson Correlation	1	-0.045
	Sig. (2-tailed)		0.834
	N	24	24
BMDiff	Pearson Correlation	-0.045	1
	Sig. (2-tailed)	0.834	
	N	24	24

Confidence Intervals

	Pearson Correlation	Sig. (2-tailed)	95% Confidence Intervals (2-tailed)[a] Lower	Upper
PinchDiff - BMDiff	-0.045	0.834	-0.441	0.365

a. Estimation is based on Fisher's r-to-z transformation.

Correlations

Notes

Descriptive Statistics

	Mean	Std. Deviation	N
PinchDiff	3.3873	12.4739	24
MADiff	7.2521	9.67231	24

Correlations

		PinchDiff	MADiff
PinchDiff	Pearson Correlation	1	0.028
	Sig. (2-tailed)		0.897
	N	24	24
MADiff	Pearson Correlation	0.028	1
	Sig. (2-tailed)	0.897	
	N	24	24

Confidence Intervals

	Pearson Correlation	Sig. (2-tailed)	95% Confidence Intervals (2-tailed)[a] Lower	Upper
PinchDiff - MADiff	0.028	0.897	-0.38	0.427

a. Estimation is based on Fisher's r-to-z transformation.

Descriptive Statistics

	Mean	Std. Deviation	N
PinchDiff	3.3873	12.4739	24
AVDiff	5.9408	11.11436	24

Correlations

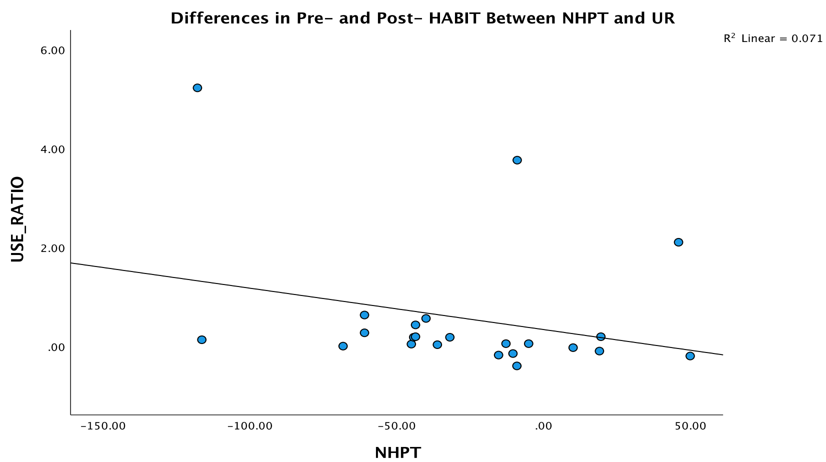
		PinchDiff	AVDiff
PinchDiff	Pearson Correlation	1	-0.06
	Sig. (2-tailed)		0.78
	N	24	24
AVDiff	Pearson Correlation	-0.06	1
	Sig. (2-tailed)	0.78	
	N	24	24

Confidence Intervals

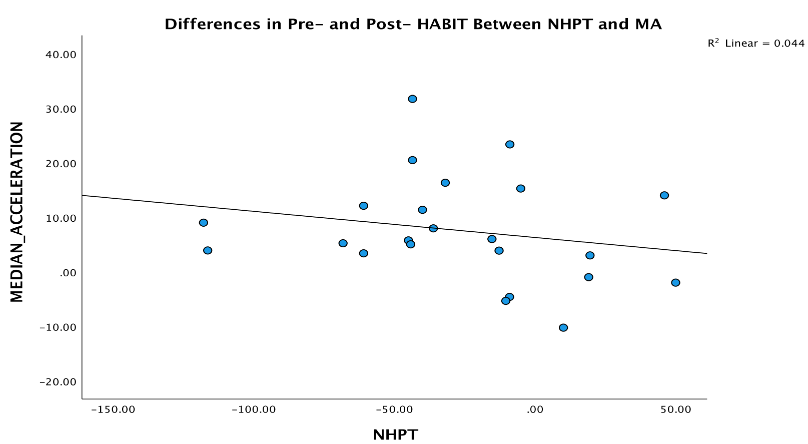
	Pearson Correlation	Sig. (2-tailed)	95% Confidence Intervals (2-tailed)[a] Lower	Upper
PinchDiff - AVDiff	-0.06	0.78	-0.453	0.352

a. Estimation is based on Fisher's r-to-z transformation.

Graph 9: Correlation between NHPT and UR



Graph 10: Correlation between NHPT and MA



Discussion

As expected, following HABIT there were notable improvements in capacity measures according to the t-tests. On average and in a clinical setting, the participants saw improvements in manual dexterity, manual coordination, and overall hand function. This is supported by the significant figures of the BBT, JHFT, and NHPT seen in Tables 3-5.

There was a 14.2% decrease in the time for participants to complete the JHFT. JHFT measures gross and fine motor hand function with its 7 different tasks. This decrease in time of completion suggests the participants in-clinic overall hand function improved following HABIT.

There was found to be a 14.4% increase in the number of blocks transferred in BBT. BBT measures in-clinic unilateral gross manual dexterity. The increase of number of blocks transferred suggests the participants saw improved in-clinic unilateral gross manual dexterity following HABIT.

NHPT only saw a 0.89% decrease in time of completion. NHPT measures finger dexterity and this data suggests that overall, there was a minor improvement in in-clinic finger dexterity following HABIT.

There were improvements seen in hand strength and pinch strength, but these measures were marked as in-significant by the p-value.

There were also significant improvements in performance measures including UR, BM, MA, and AV. Following HABIT, the average UR saw a 5.4% increase. UR is the ratio between the minutes of use calculated for the non-dominant and the dominant limb respectively, regardless of the intensity of the movement performed. UR of 1.0 indicates equal usage between both limbs. This means participants were using their affected arm on average, 5.4% more that pre- HABIT in real-world activities.

There was a 12.3% increase in average BM. BM reflects the intensity of activity across both UEs and was calculated by summing the vector magnitude of the nondominant and dominant UEs for each second of activity. This means on average; participants were moving their UE at faster speeds than pre- HABIT.

A 32.1% average increase in MA was also discovered. MA is simply the median of acceleration values recorded on the accelerometer. This data once again supports that participant initial movements at higher median speeds in real-world activities following HABIT.

There was also an 8.4% increase in AV. AV tracks the difference in the average acceleration within different points along the path of the participants UE. This means participants are accelerating the UE at higher rates which would increase the variability in acceleration.

These improvements mark an increase relative contribution of affected UE to bimanual tasks in terms of hours and magnitude post- HABIT. These results indicate that HABIT improves UE capacity as well as performance independently of each other in children with UCP. However, hand and pinch strength improvements were non-significant illustrating that HABIT may not improve UE strength capacity of children with UCP. MR improvements were also non-significant which could indicate that HABIT may not improve this accelerometer derived performance variable in children with UCP.

Using the Person's correlation coefficient there was found to be an overall very weak correlation between capacity measures and performance measures. There was positive very weak correlation between BBT, and all accelerometer derived variables as seen in Table 11. There was positive very weak correlation between JHFT and UR, MA, and BM and a negative very weak correlation between JHFT and AV as seen in Table 12. There was also a negative very weak correlation between pinch strength and UR and MA with a positive very weak correlation between pinch strength and MA, BM and AV as seen Table 15. NHPT saw a negative very weak correlation with BM and AV as seen in Table 13. Correlation between hand strength, pinch strength and MR were not considered due to all being considered non-significant figures ($p > 0.05$). This means that there is little to no correlation between these capacity measures and performance measures. The strongest correlations recorded was a negative weak correlation between NHPT and UR and MA as seen in graphs 9 and 10. This means that the faster the NHPT times and higher UR and MA recordings. These results demonstrate that accelerometers are a valid and objective tool in measuring real-world performance, when compared to self-report data. In conclusion, In-clinic capacity improvements do not correlate with real-world performance improvements. Further research on children with UCP should take this into account.

One limitation of this study is small sample size of 24 children. This number of children was difficult to manage and there were a ton of moving parts to run a 30-hour long HABIT camp. This in mind, this is a respectable sample size, but it is not the best for statistical analysis. Further research needs to be done to increase the sample size, meaning more HABIT camps should be conducted to collect more data on capacity measures and performance measures. This study also only measures immediate effects post- HABIT. There needs to be further research on the retention of the real-world performance gains.

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