# Efficacy of a hand–arm bimanual intensive therapy (HABIT) in children with hemiplegic cerebral palsy: a randomized control trial

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**Children with hemiplegic cerebral palsy (CP) have impairments in bimanual coordination above and beyond their unilateral impairments. Recently we developed hand–arm bimanual intensive therapy (HABIT), using the principles of motor learning, and neuroplasticity, to address these bimanual impairments. A single-blinded randomized control study of HABIT was performed to examine its efficacy in children with hemiplegic CP with mild to moderate hand involvement. Twenty children (age range 3y 6mo–15y 6mo) were randomized to either an intervention (*n*=10: seven males, three females; mean age 8y 7mo, SD 4y) or a delayed treatment control group (*n*=10: seven males, three females; mean age 6y 10mo, SD 2y 4mo). Children were engaged in play and functional activities that provided structured bimanual practice 6 hours per day for 10 days. Each child was evaluated immediately before and after the intervention, and again at 1-month post-intervention. Children in the intervention group demonstrated improved scores on the Assisting Hand Assessment, increased involved extremity use measured using accelerometry and a caregiver survey, bimanual items of the Bruininks–Oseretsky Test of Motor Proficiency, and the simultaneity of completing a draw-opening task with two hands ($p<0.05$ in all cases). The results suggest that for this carefully selected subgroup of children with hemiplegic CP, HABIT appears to be efficacious in improving bimanual hand use.**

Children with hemiplegic cerebral palsy (CP) often have impairments in function of the involved upper extremity that affect their independence and quality of life. However, there is some evidence that the impaired hand function is not static during development.[1,2] In fact, the rate of development of the involved hand of children with CP largely parallels that of typically developing children.[3] Thus, one key to rehabilitation is to alter the rate of development so that children with CP more closely approximate the functional independence and social integration observed in typically developing children. Unfortunately, evidence-based treatments of impaired hand function are largely lacking.[4] Children with hemiplegia may benefit from intensive unimanual practice,[5] intensive contemporary occupational therapy[6] or goal-directed training combined with botulinum toxin.[7] One recent treatment approach providing intensive unimanual practice, constraint-induced movement therapy (CIMT), has shown promise for the improvement of unimanual hand function. CIMT restrains the non-involved upper extremity while the involved extremity engages in intensive targeted practice.[8] Thus far, the results of pediatric CIMT studies suggest promise for this approach in children with hemiplegia.[9–13]

Despite the considerable attention pediatric CIMT has received, there are several conceptual problems and limitations. First, restraining a child's non-involved extremity (especially with casts) is potentially invasive. Elicited practice, rather than restraint, is responsible for improved motor performance.[14] Second, CIMT was developed to overcome learned non-use in adults with hemiplegia while children with hemiplegia may have never effectively learned to use their involved extremity. Thus, CIMT must be modified to be developmentally focused.[15] Most importantly, CIMT is a unimanual intervention, and increased functional independence in the child's environment requires use of both hands in cooperation.

Children with hemiplegic CP have impaired bimanual coordination[16–19] beyond their involved upper extremity impairments, and these impairments may underlie some of the functional limitations that decrease their independence. There is some suggestion that initial unimanual practice can transfer to improvements in bimanual coordination,[9,10] suggesting that treatment can ameliorate their poor bimanual coordination. However, this might be best accomplished by practicing bimanual skills directly.

Based on the above premise, we developed a bimanual intervention, 'Hand–arm bimanual intensive therapy' (HABIT), addressing the specific upper extremity impairments in congenital hemiplegia.[20] HABIT is a form of functional training that takes advantage of the key ingredient of CIMT (intensive practice), but focuses on improving coordination of the two hands using structured task practice embedded in bimanual play and functional activities. It uses principles of motor learning (practice specificity, types of practice, feedback),[21] and principles of neuroplasticity (practice-induced brain changes arising from repetition, increasing movement complexity, motivation, and reward).[22,23] The purpose of the present study was to examine the efficacy of HABIT in improving the frequency and quality of bimanual hand use in children with hemiplegic CP.

## Method

### PARTICIPANTS AND RECRUITMENT

The following inclusion criteria were established based on those used in our prior CIMT studies in CP:[10,24] (1) ability to extend the wrist greater than 20° and the fingers at the metacarpophalangeal joints greater than 10° from full flexion; (2) greater than 50% difference between the involved and non-involved hand on the Jebsen–Taylor Test of Hand Function provided during screening; (3) the ability to lift the involved arm from the table surface to a surface six inches above; and (4) score within one standard deviation of the mean on the Kaufman Brief Intelligence Test. Children were excluded who had: (1) health problems unassociated with CP; (2) current/untreated seizures; (3) visual problems that could interfere with performing the intervention or testing; (4) severe muscle tone (Modified Ashworth score greater than 3.5); (5) orthopaedic surgery on the involved upper extremity; (6) dorsal rhizotomy; (7) botulinum toxin therapy in the upper extremity musculature during the past 6 months or who intend to receive it within the period of study; and (8) intrathecal baclofen.

Figure 1 shows the recruitment process. Sixty-two children with hemiplegic CP (age range 3y 6mo–15y 6mo) were initially screened by telephone or e-mail in order to determine the age, diagnosis, pertinent medical history, and the frequency and duration of current rehabilitation services. These children were recruited from the greater metropolitan New York city area, through the HABIT website (http//: www.tc.edu/centers/cit/), and through various electronic bulletin boards. Thirty-eight did not meet the inclusion criteria. Of these, 34 potential participants did not qualify as determined by telephone/e-mail interview, reasons being: 10 not interested or able to commit to study procedures or travel for evaluation and/or intervention; eight for wrong age; four were too severe; two had received BOTOX; two were concurrently participating in another treatment; and eight for wrong diagnosis. Four additional participants were excluded after subsequent physical screening, reasons being: two for wrong diagnosis; one for poor cognition; and one for hand impairment being too mild (less than 50% difference between two hands). Two participants who qualified after physical screening declined participation. Randomized to study (*n*=22): HABIT intervention group (*n*=11), with

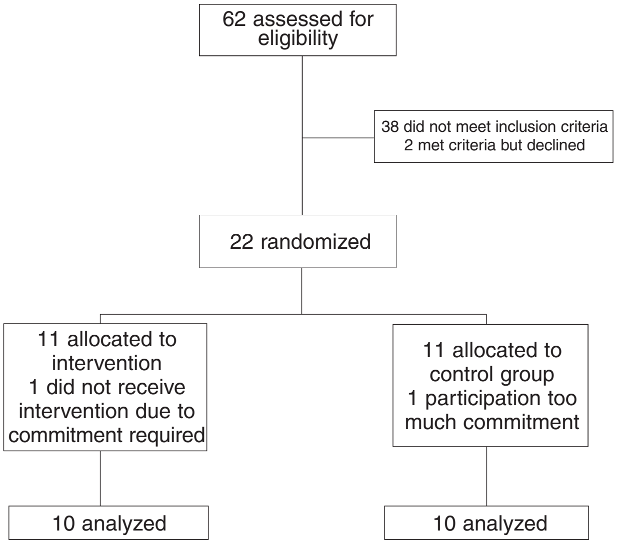

**Figure 1:** *Progress through the stages of hand–arm bimanual intensive therapy study, including flow of participants, withdrawals, and inclusion in analyses.*

**Table I: Study participants**

| *Child* | *Group* | *Involved side* | *Sex* | *Age (y:mo)* | *Jebsen pretest(s)* | *AHA pretest* | *TPD (mm)* |
|---|---|---|---|---|---|---|---|
| 1 | Intervention | R | M | 6:5 | 632 | 43 | NR |
| 2 | Intervention | R | F | 5:10 | 564 | 62 | 6 |
| 3 | Intervention | R | M | 4:7 | 519 | 56 | 5 |
| 4 | Intervention | R | M | 8:10 | 507 | 55 | 7 |
| 5 | Intervention | R | M | 13:7 | 505 | 59 | 5 |
| 6 | Intervention | R | F | 7:9 | 432 | 58 | 4 |
| 7 | Intervention | R | M | 13:5 | 361 | N/A | 7 |
| 8 | Intervention | R | M | 4:5 | 257 | 57 | NR |
| 9 | Intervention | L | F | 6:3 | 189 | 68 | NR |
| 10 | Intervention | L | M | 15:3 | 101 | 62 | 4 |
| 11 | Control | L | F | 4:0 | 720 | 50 | NR |
| 12 | Control | L | F | 3:9 | 516 | 49 | NR |
| 13 | Control | R | M | 5:5 | 336 | 56 | 4 |
| 14 | Control | R | M | 7:11 | 196 | 65 | NR |
| 15 | Control | L | M | 7:3 | 161 | 56 | 9 |
| 16 | Control | L | F | 6:2 | 145 | 57 | 3 |
| 17 | Control | R | M | 7:6 | 129 | 58 | 3 |
| 18 | Control | L | M | 10:1 | 110 | 76 | 7 |
| 19 | Control | R | M | 5:1 | 77 | 81 | 2 |
| 20 | Control | R | M | 10:6 | 50 | 66 | 5 |

Participants are listed in descending order based on Jebsen–Taylor times at pretest. L, left; R, right; Jebsen, Jebsen–Taylor Test of Hand Function[31] pretest score; AHA, Assisting Hand Assessment[26] pretest raw score (out of 88); TPD, two-point discrimination; NR, not reliable; N/A, not available.

one participant withdrawing before receiving intervention, control group ($n$=11) and one control participant withdrawing after first test (pretest). Lost to follow-up: one child in the treatment group (participant 9) and one child in the control group (participant 11) failing to attend the 1-month posttest. Twenty children completed the study (Table I) starting in July 2004 and ending in July 2006. Randomization was performed in groups of four children (i.e. rolling admission) by the research assistant. Because all children needed to initiate wrist and finger movement as an inclusion criterion, all children demonstrated mild to moderate hand (Zancolli Type IIa)[25] involvement upon screening. Children in the control group did not initially receive treatment, but were subsequently crossed-over to receive treatment after their participation. Children in both groups continued to receive usual and customary care that they were receiving elsewhere. Informed consent was obtained from all children and their caregivers. The study was approved by Teachers College, Columbia University Institutional Review Board.

### HABIT PROCEDURES

The intervention[20] was provided on 10 out of 12 consecutive days during summer (typically 2wks of weekdays) at our university with groups of four children. At the end of each day, each child in the treatment group went home with an exercise program that involved bimanual practice for 1 hour, which was extended to 2 hours per day for 1 month after the intervention. Parents kept activity logs to monitor compliance. This practice began a regular routine of involved-hand use in the child's environment so that parents or caregivers could solve problems with staff members, with the hope that this interface would continue beyond the intervention.

We established a list of age-appropriate fine motor and manipulative gross motor activities that required the use of both hands.[20] Specific activities were selected by considering the role of the involved limb in the activity (e.g. stabilizer, manipulator, active/passive assist). Task demands were graded to allow for success, and difficulty was progressed with specific rules associated with success. Task performance was recorded, and both positive reinforcement and knowledge of performance were used to motivate performance and to reinforce target movements.

Movement deficits of the involved upper extremity and bimanual coordination problems were determined during the pre-intervention evaluation. Bimanual activities were then selected that improved these movement deficits and engaged the child in activities of increasingly complex bimanual coordination. Directions were given to the child before the start of each task in order to specify how each hand would be used during the activity and to avoid use of compensatory strategies (performing the task unimanually with the non-involved extremity). If a child attempted to use the non-involved hand inappropriately (e.g. using compensatory strategies as a substitution for involved hand use), the task was paused and the child was reminded of the task rules. Interventionists were instructed to avoid urging the child to use his/her involved hand and avoid physically inhibiting use of the non-involved hand during an activity.

Children were engaged in two types of structured practice during the intervention: whole task and part task practice. During performance of whole task practice, activities were performed continuously for at least 15 to 20 minutes but no longer than 1 hour. Targeted movements and spatial and temporal movement coordination were practiced within the context of completing a task (e.g. playing a board game). Part task practice involved practicing a targeted movement exclusive of other movements. It is analogous to shaping in psychology and CIMT literature.[15] Specifically, symmetrical bimanual movements were often used to elicit a targeted movement (e.g. putting game pieces away simultaneously with each hand) because of the simplicity of control. The frequency of successful task completion (the number of times the child succeeded in 30s) was recorded, and the task was repeated five times.

Task difficulty was graded as the child's performance improved by requiring greater speed or accuracy, or by providing tasks that required more skilled use of the involved hand and arm (e.g. moving from activities in which the involved limb acted as a stabilizer to activities that required manipulative skills). Interventionists altered constraints to grade tasks according to desired target movements (e.g. they built up the grasp surface of an object by adding tape and removed it as grasp improved). Emphasis was placed on completing each movement with the involved upper extremity in the same way as the non-dominant hand of a typically developing child (i.e. as a stabilizer or manipulator). Practice was structured to promote increased intensity: the involved hand was not merely used to assist in every activity.

### MEASUREMENT

Each participant was evaluated once before (pretest) and twice after the intervention within the first week after the intervention ('immediate') and at 1 month (posttest). The same evaluator, blind as to group assignment (and verified orally after data collection), performed all testing for a specific child. The following tests were used.

#### *Assisting Hand Assessment*

The Assisting Hand Assessment (AHA; version 4.3) is a newly developed Rasch-built instrument that measures and describes the effectiveness with which a child with unilateral disability makes use of their affected (assisting) hand during bimanual activities.[26] The AHA is scored from video recordings of 12 to 14 play activities. These activities are subsequently scored based on 22 predefined items using a four-point rating scale. The raw score sum ranges from 22 (low ability) to 88 (high ability). Rasch analysis provides measures of equal intervals in logits (log odds probability units) by converting ordinal rating-scale observations through a logarithmic transformation based on probabilities.[9] The AHA served as the primary outcome variable. The assessment has been recently shown to have good validity[26,27] and reliability (0.97 interrater and 0.99 intrarater)[28] and is sensitive to change.[9]

#### *Accelerometry*

After data collection on the first few participants, we noted that the AHA rates quality of bimanual use, but does not quantify specifically the frequency with which each hand is used during the task. Therefore, for the remaining participants (numbers 5–20) accelerometers were used during the performance of the AHA to measure frequency of use of each extremity during the AHA testing session.[29] Children wore an activity monitor (Manufacturing Technology Inc. Fort Walton

Beach, FL, model 7164; 5.1cm x 2.6cm x 1.5cm, 42.9g) on each wrist during the AHA test session. Twelve activities were performed consistently across sessions. The accelerometers were fastened to the wrist using custom-made Velcro wristbands. The units sample at 10Hz and store summed values in random-access memory, which are subsequently downloaded to a personal computer. The number of accelerations is measured as activity counts (0.01664g for an acceleration of 2.13g directed parallel to the unit's x-axis with a frequency of 0.75Hz). We used these counts along with a synchronized video to determine the percentage of time each hand was used while performing the 12 activities.

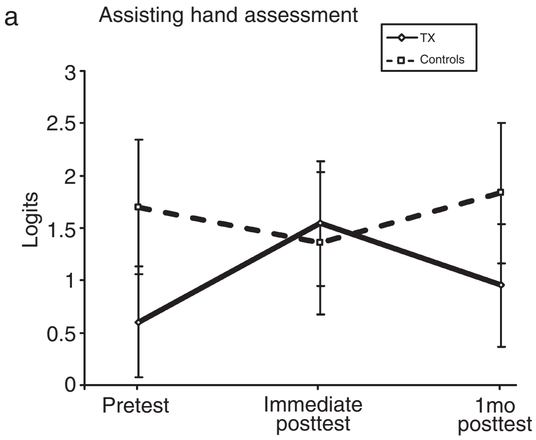

**Figure 2a:** *Mean (SEM) scores (in logits) on the Assisting Hand Assessment for the hand–arm bimanual intensive therapy treatment (TX, $n=9$, solid line) and control ($n=10$, dashed line) groups at each testing session.*

*Bruininks–Oseretsky Test of Motor Proficiency*

We selected six bimanual items across the bilateral coordination, upper limb coordination, and upper limb speed and dexterity subtests of the Bruininks–Oseretsky Test of Motor Proficiency.[30] This is a standardized test of gross and fine motor function for children to measure changes in hand use. Specifically we used the following items: placing pennies in a box with each hand simultaneously, stringing beads, sorting cards, catching a bounced ball with two hands, catching a thrown ball with two hands, and simultaneously making crosses and vertical lines with each hand.

*Caregiver Functional Use Survey*

A Caregiver Functional Use Survey (CFUS) was designed to assess caregivers' perceptions of how much and how well their child used the involved upper extremity during 10 unimanual and 10 bimanual tasks (modified from Charles et al.[10]). Each item was rated on a six-point (0–5) Likert scale on the frequency and quality of hand use. Note that parents were not blinded as to treatment group.

*Jebsen–Taylor Test of Hand Function*

To assess unimanual upper extremity efficiency, the Jebsen–Taylor Test of Hand Function[31] was used for the involved extremity. The test was modified by eliminating the writing task and capping the maximum allowable time to complete each of the six timed items at 2 minutes (maximum time to complete all items was 720s) to reduce frustration levels associated with failure to accomplish the task.

*Kinematics of a drawer-opening task*

To characterize changes in movement patterns during a bimanual task, we recorded the kinematics of the two hands

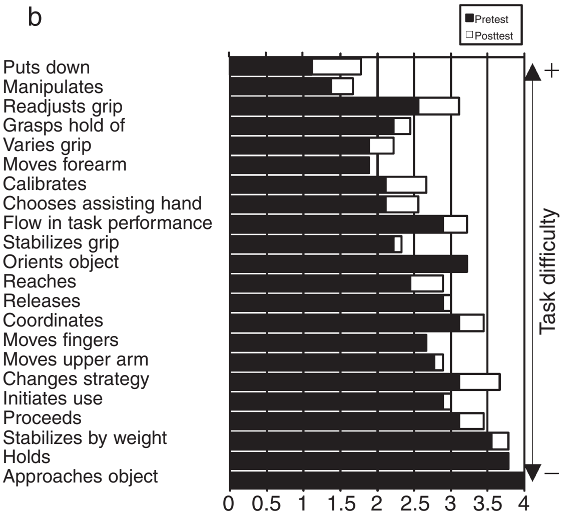

**Figure 2b:** *Raw scores for each of the 22 test items during the pretest (black) and immediate posttest (white). Items are scored from 1 to 4 and are ordered in accordance with hierarchy of difficulty based on test construction.*

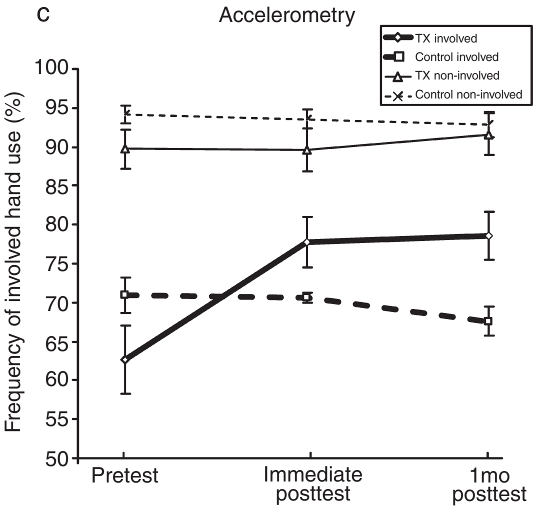

**Figure 2c:** *Frequency of upper extremity movement as a percentage of task times for the involved (bold lines) and non-involved (thin lines) hands of the hand–arm bimanual intensive therapy treatment (TX, solid lines) and control (dashed lines) groups. Higher scores represent better bimanual performance in all three plots.*

as participants opened a drawer and manipulated its contents. Participants were seated 15cm in front of a table with their elbows flexed at right angles with their hands palm-down on the edge of the table, 30cm apart.[16] They were asked to open a spring-loaded drawer (load 0.3kg) with one hand (drawer hand) and to insert their contralateral hand (task hand) in the drawer to activate a 14cm x 10cm push-button light switch. The drawer had a loop handle (9cm in length and 3cm in depth) and was placed in front of the participant at midline 30cm from the edge of the table. Each trial was initiated in response to an auditory 'go' signal and ended after they activated the light switch inside the drawer. The task was performed with each hand opening the drawer (involved and non-involved) at self-pace. Five trials were then collected for each condition (10 trials). Movement of the wrists was measured using electromagnetic position sensors (Polhemus Fastrack, Colechester, VT, 60Hz, 1mm resolution). In a prior study[16] we had documented that the control variable most greatly affected in children with hemiplegic CP is goal synchrony, defined by the time difference between the drawer hand completing the opening of the drawer and the task hand reaching inside the drawer (wrist tangential velocity fell below a criterion of 2.6cm/s): the sequentiality of task completion. Thus this measure served as the outcome measure for this task.

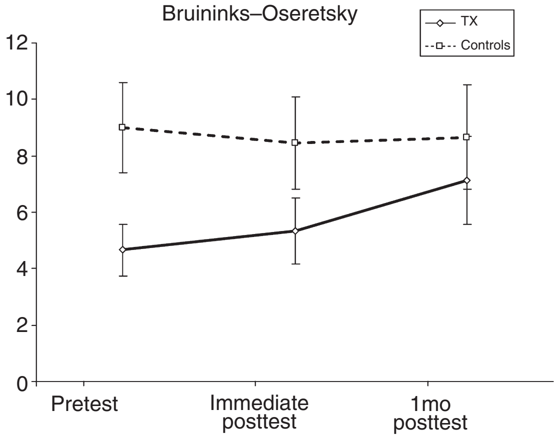

**Figure 3:** *Mean (SEM) score on the six bimanual items of the Bruininks–Oseretsky Test of Motor Proficiency[30] for the hand–arm bimanual intensive therapy treatment (TX, solid line) and control (dashed line) groups at each testing session. Higher scores correspond to better performance.*

### DATA ANALYSIS

We were interested in both the changes in function immediately after the intervention and whether these changes were retained subsequently. Thus, a 2 (groups) x 3 (sessions, pretest vs two posttests) ANOVA with repeated measure on the second factor was used to evaluate differences for each measure immediately after the intervention. An overall group by testing session interaction tested whether the average time course differed between groups. This approach effectively controlled for differences at baseline between the two groups. Tests of simple effects were used for post-hoc analysis. We also performed these tests on log-transformed data and performed non-parametric statistics, with the same qualitative results.

Two participants, one from each group (participants 9 and 11), did not show up for the 1-month posttest. Their data are included in statistical analysis but are not included in Figures 2 to 5. Furthermore AHA data from one child in the treatment

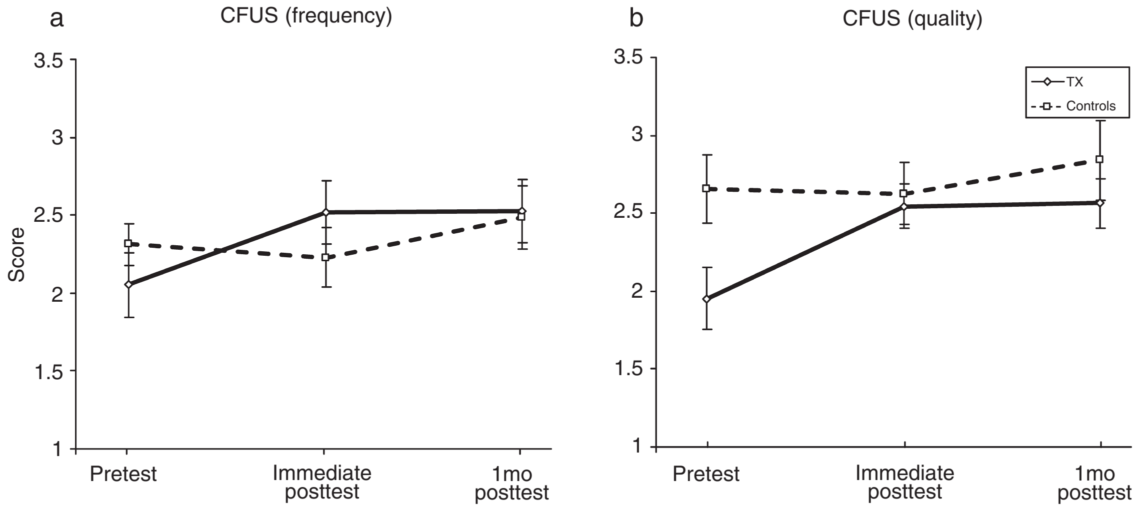

**Figure 4:** *Mean (SEM) score on the Caregiver Functional Use Survey (CFUS)[10] for the hand–arm bimanual intensive therapy treatment (TX, solid line) and control (dashed line) groups at each testing session. (a) Frequency of use, and (b) quality of movement. Scores represent average ratings on 10 bimanual items and 10 unimanual items from 0 (never used) to 5 (used as frequently or as well as the non-involved hand). Higher scores correspond to increased quality and quantity of involved extremity use.*

group (number 7) was omitted because of poor video quality preventing accurate assessment, and kinematic data on the drawer task was omitted for one child in the treatment group (number 3) because he was unable to complete the task.

## Results

### TREATMENT INTENSITY

Overall, children in the treatment group spent an average of 73% (44/60h) of the time during the intervention in structured practice. Of this time, 18% was spent in part task practice and 82% in whole task practice. The remaining time in which children were not in structured practice was spent choosing activities, transitioning between tasks, toileting, etc. No adverse events were reported. In addition, the children used their involved upper extremity in home practice an average of 1.4 hours per 10 days during the intervention and 1.7 hours per day for the one month after the intervention.

### CHANGES IN MOVEMENT EFFICIENCY

Figure 2a shows the results of the Assisting Hand Assessment (scores in logits). Children in the treatment group had improved scores initially after the intervention whereas the scores for the controls did not change significantly (group x testing session interaction $F[2,30]=5.162$, $p<0.012$, effect size $[\eta^2]=0.256$). The scores increased for all but one child (number 5). They decreased by the 1-month posttest, although they were still significantly higher than at the pretest. The scores for each item during the pretest (black bars) and the immediate posttest (white bars) for each item of the AHA (ordered according to difficulty according to the test construction[26]) are shown in Figure 2b. As seen in the figure, the children generally had higher scores for easier items at the pretest. There were increases in 17 of the 22 test items, with changes ranging from zero to 0.66 (out of 4), although they did not appear to be related to difficulty. The largest increases occurred for putting down objects, adjusting and calibrating grip, and changing strategies.

Figure 2c shows the accelerometry results for the children who wore accelerometers ($n=6$ TX, 10 controls) during performance of the AHA test. The percentage of time the involved extremity was used increased from 62.6 to 77.8% of the task performance for the children who received HABIT, whereas the percentage of time the controls used their involved extremity stayed about the same (about 70%; group × testing session interaction, $F[2,24]=16.565$, $p<0.001$, $\eta^2=0.580$). The increase was observed in all six children in the HABIT treatment group and they were maintained throughout the 1-month testing period. Increases were noted on 11 of the 12 items, with only opening a music box slightly decreasing (85–81%). Use of the non-involved extremity remained the same across testing sessions (90–94%) in both groups. Interestingly, the change in amount of use did not correlate with the change in AHA scores from pre- to postintervention ($r=-0.23$), indicating that amount of use is independent of quality of use.

As shown in Figure 3, the control group had higher (better) scores on the Bruininks–Oseretsky Test at the pretest. Children in the treatment group improved 'immediately' and continued to improve through the 1 month posttest whereas the scores of children in the control group remained relatively stable (group × testing session interaction, $F[2,32]=4.28$, $p<0.023$, $\eta^2=0.211$).

Whereas participants in the control group overall had faster times on the Jebsen–Taylor Test of Hand Function at the pretest (243s vs 406s, $p<0.014$; not shown), there were no significant changes for the HABIT treatment group (group × testing session interaction, $p>0.05$), indicating that there was not improvement in unimanual hand function. There was also no change in Zancolli grade for any of the children.

### CHANGES IN ENVIRONMENTAL FUNCTION

Caregivers of children in the HABIT treatment group perceived greater improvement in amount of use than caregivers of children in the control group as measured by the CFUS ($F[2,32]=4.22$, $p<0.024$, $\eta^2=0.209$; Fig. 4). This improvement was maintained at the 1-month posttest. The quality of movement also improved as perceived by caregivers for the treatment group more than children in the control group ($F[2,32]=4.756$, $p=0.016$, $\eta^2=0.229$).

### KINEMATICS

The drawer opening task was used to determine whether there was a change in movement patterns. As seen in Figure 5, the goal synchronization time decreased nearly threefold for the children in the treatment group but not for the control group. There was a main effect of testing session ($F[2,30]=5.346$, $\eta^2=0.263$) although the group by testing session interaction failed to reach significance ($p<0.055$), likely because of the large variation between children in the HABIT treatment group at pretest.

### PREDICTORS OF OUTCOME

Although the initial Jebsen–Taylor scores and the scaled (normalized) AHA scores were significantly correlated with each

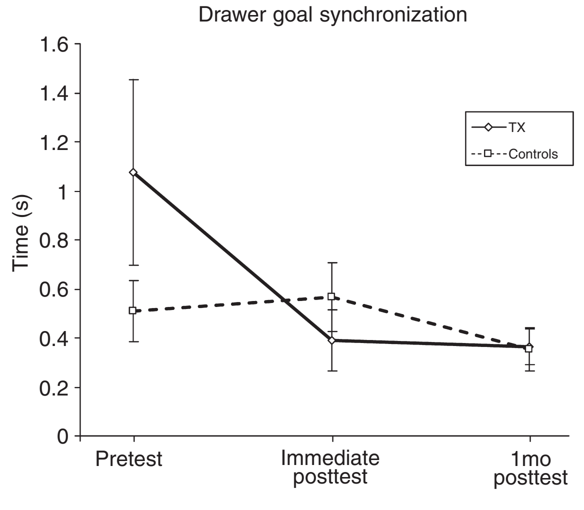

**Figure 5:** *Mean (SEM) goal synchronization duration (time difference between the two hands completing the task) during the drawer opening task for the HABIT treatment (TX, solid line) and control (dashed line) groups at each testing session. Lower times correspond to improved performance.*

other ($r$=–0.55), neither accounted for a significant amount of variance in the improvement on the AHA scores from pre- to postintervention when entered into a regression model.

## Discussion

### IMPROVEMENTS IN BIMANUAL PERFORMANCE

Previously it is has been shown that unimanual gains may be achieved after intensive unimanual training associated with CIMT.[12,13] Thus our findings are consistent with other studies providing intensive practice, although we show that intensive bimanual training can improve the quality and quantity of bimanual hand use. This suggests specificity of training, and is consistent with motor learning theories.[33]

There were significant changes on all tests, although there was only a large effect size (>0.5) for the frequency of affected hand use (accelerometry). There are several possible factors limiting the magnitude of our findings. First, all children continued to receive their usual and customary care treatment. However, this is unlikely to greatly affect our results because both groups continued their regular rehabilitation and the scores for the control group remained stable. Another possible factor was that four of the children in the treatment group (participants 3, 4, 5, and 7) and six children in the control group (participants 12, 14, 15, 17, 18, and 20) reported receiving CIMT before participation. In fact, the AHA raw scores for children who received prior CIMT improved less (mean 4.3, range –1 to 9) than the scores for children who had never received CIMT (mean 11.3, range 4–24). Thus, they may well have reached a ceiling effect. Ideally we would have liked to have excluded children who had received prior CIMT, but this is unfeasible given the growing number of children who received it through prior participation in other studies or through their routine rehabilitation services.

HABIT is complementary to (rather than a substitute for) other treatments of the upper extremity as it only occurs during a short (10d) period. Thus we believe that even a small to moderate effect size for such a short treatment duration represents a success. Nevertheless HABIT may need to be performed over a longer period or repeated during childhood and adolescence with the latter having been shown to be beneficial using CIMT.[32]

Although we found improvements in quality of bimanual hand use (both on the AHA and Bruininks–Oseretsky Test) and frequency of use (accelerometry and caregiver survey), surprisingly these changes did not correlate. This emphasizes the need to measure both of these components separately. It should be noted, however, that the extent to which quality and quantity are related may be task dependent. For many tasks, increased quality may in fact require the ability to stabilize an object with the non-involved extremity (i.e. keep it still). For others, active manipulation of both hands may be desirable. Our findings of an increased amount of involved extremity use during AHA (which progresses in complexity from passive stabilizer to active assist) is interesting, although this assessment measures much more than frequency of use.[26]

### BIMANUAL TREATMENT IN CHILDREN

HABIT was designed for use in children with unilateral upper extremity impairments based on our experience with CIMT[10,11,15] to target specific deficits, including impairments in spatial and temporal control,[16–19,34] and findings of developmental disuse, specifically during bimanual activities.[10] HABIT uses principles of practice (specificity of training[33]) as well as principles of plasticity.[20,22,23] The corticospinal system underlying human dexterity is capable of considerable reorganization after damage, likely underlying recovery of function.[35]

Bimanual interventions in adults with stroke have been conducted[36,37] although these studies have largely used repetitive or cyclical (e.g. repetitive cycling with the two hands) tasks or practice of activities of daily living. Although the part practice tasks we use often involve symmetrical tasks to practice targeted movements, most of the time is spent performing whole practice of functional/play activities. To motivate children, participation must be fun. Thus, HABIT is consistent with the recent emphasis on functional training and practicing predefined goals in therapeutic environments.[38–41] HABIT's emphasis on functional activity performance also directly addresses the recent modification of the definition of CP, whereby it is considered a 'disorder of movement and posture causing activity limitation'.[42,43]

Although HABIT is potentially less invasive than CIMT because there is an absence of restraint, in our experience, administering it is often more difficult for the interventionists. Children with hemiplegia are strikingly adept at using only their non-involved extremity to perform tasks for which their typically developing peers require both hands, even if it is at the cost of efficiency (e.g. performing tasks sequentially or using body parts as a brace). During CIMT, the restraint forces the participant to use the involved extremity to accomplish the task, with the drawback that the tasks must be unimanual. HABIT tasks must be bimanual to train specific coordination skills. In many instances we observed spatial and temporal dyscoordination associated with using the two extremities together. Often their natural tendency would be to over-compensate with their non-involved extremity (e.g. reach into the involved extremity's hemispace). Although the interventionist could simply remind the child to use the involved extremity, this strategy is less effective than desirable as children quickly attenuate. Thus, far more attention must be provided to the choice of activities and structuring the environment. Providing rules before an activity, with occasional reminders of the rules (rather than direct prompts), are far more effective because the child is asked to verbally agree before participation. Thus the interventionist must use these rules and the environment as a new type of restraint.

One aspect that does make it easier than CIMT is the fact that bimanual activities are generally more motivating. In fact, compared with our prior CIMT randomized trial,10 children spent about 25% more time on tasks during the HABIT intervention. Furthermore, compliance with the home exercise program was more than twice as high during the intervention and more than 50% greater after the intervention, likely because of the easier task choices for HABIT (e.g. video games). Thus, motivational and social aspects of types of practice may need to be considered in intervention design.

### CLINICAL IMPLICATIONS

To our knowledge, HABIT is the first functionally-based intensive bimanual training paradigm for children. Here we provide preliminary evidence that training bimanual skills can improve bimanual function. Thus, it would seem that the best approach to determine the most appropriate treatment might be to start with the end-goal in mind. We believe that for hemiplegic CP, the most appropriate goal in terms of hand function would be increased quality and quantity of bimanual use.

Overall, this intervention showed improved involved upper extremity bimanual function in this select group of children with hemiplegic CP. However, the results are limited in that the sample size was small and the children in the treatment group were by chance more impaired. Although this does not negate our findings because only the treatment group shows improvement and we have previously demonstrated stability in most of these measures in controls across time regardless of severity,[10] larger studies using stratified randomization across a more diverse participant population with a long-term follow-up are required for future study. A control group that receives alternative treatment would also be desirable. The appropriate age and impairment levels need to be identified and factors such as side and location of lesion, attention span, balance of whole versus part practice, optimal dosage, and whether best to provide in groups or individually at home all need to be considered to ultimately define the most efficacious rehabilitation strategy.

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