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Efficacy of Constraint-Induced Movement Therapy on Involved Upper-Extremity Use in Children With Hemiplegic Cerebral Palsy Is Not Age-Dependent

Andrew M. Gordon, PhD[a,b], Jeanne Charles, PhD, MSW, PT[a], Steven L. Wolf, PhD, PT, FAPTA[c]

[a]Department of Biobehavioral Sciences, Teachers College, and [b]Department of Rehabilitation Medicine, College of Physicians and Surgeons, Columbia University, New York, New York; [c]Department of Rehabilitation Medicine, Emory University School of Medicine, Atlanta, Georgia

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ABSTRACT

OBJECTIVES. Constraint-induced (CI) movement therapy has been shown recently to be promising for improving upper-limb function in children with cerebral palsy (CP). Because little is known about patient characteristics predicting treatment efficacy, not all children may benefit from this intervention. Here we examine the relationship between efficacy of a child-friendly form of CI therapy and age on involved upper-extremity function.

DESIGN. Twenty children with hemiplegic CP age 4 to 13 years received CI therapy and completed evaluations. Based on established functional and neuromaturational changes in hand skill development, the children were divided into a "younger group" (age 4–8 years, $n = 12$) and "older group" (age 9–13 years, $n = 8$). Children wore a sling on their noninvolved upper extremity for 6 hours per day for 10 of 12 consecutive days, during which time they were engaged in play and functional activities. Each child was evaluated by trained evaluators who were blinded to the fact that the children received treatment. The evaluations took place once before the intervention and at 1 week, 1 month, and 6 months after the intervention. Efficacy was examined at the movement efficiency (Jebsen-Taylor Test of Hand Function, subtest 8 of the Bruininks-Oseretsky Test of Motor Proficiency), environmental (caregiver frequency and quality of involved upper-limb use), and impairment (strength, tactile sensitivity, and muscle tone) levels.

RESULTS. Children in both age groups had significant improvements in involved hand-movement efficiency and environmental functional limitations, which were retained through the 6-month posttest. However, there were no differences in efficacy between younger and older children. Both hand severity and the children's behavior during testing (number of redirections), with the latter serving as a reasonable correlate for attention during the intervention, were related to changes in performance in the younger group but not in the older group.

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Key Words
constraint-induced therapy, cerebral palsy, children, hand and arm movement, rehabilitation, hemiplegia, forced use

Abbreviations
CP—cerebral palsy
CI—constraint-induced
CFUS—Caregiver Functional Use Survey

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Address correspondence to Andrew M. Gordon, PhD, Department of Biobehavioral Sciences, Box 199, Teachers College, Columbia University, 525 W 120th St, New York, NY 10027. E-mail: ag275@columbia.edu

CONCLUSIONS. The results suggest that the intensive practice associated with CI therapy can improve movement efficiency and environmental functional limitations among a carefully selected subgroup of children with hemiplegic CP of varying ages and that this efficacy is not age-dependent.

IMPAIRED HAND FUNCTION is a major disability in children with hemiplegic cerebral palsy (CP). As a result, children with hemiplegic CP often fail to use the involved upper extremity and learn to perform most tasks exclusively with their noninvolved upper extremity (ie, developmental disuse).[1] This disuse, in turn, may lead to additional impairments secondary to neural damage associated with CP. Interestingly, we have found that, in the laboratory environment, repetitive practice of a motor task with the involved hand can result in improved performance[2,3] in a relatively short time period. This observation suggests that the involved upper extremity is amenable to treatment and that intensive practice may be beneficial to improve function.

A recent therapeutic intervention, constraint-induced (CI) movement therapy, seems promising for children with hemiplegic CP. It provides an opportunity for such practice with the involved hand and arm as a result of restraining the noninvolved upper extremity along with providing structured practice (including the essential elements of shaping and repetitive practice) with the involved upper extremity[4–6] (reviewed in ref 6). Currently, there is a national clinical trial (Extremity Constraint-Induced Therapy Evaluation [EXCITE]) underway to test the efficacy of CI therapy for people with subacute stroke.[7] To date, there have been 15 studies (9 of which were case studies) of CI therapy in children (see refs 8–15 for examples and ref 16 for review). All of the studies reported positive results, thus suggesting that CI therapy and forced use may be appropriate for a range of ages that span across motor developmental levels. However, the studies all differed regarding the type of restraint, restraint duration, type of practice (structured or unstructured), and outcome measures (reviewed in ref 16). Thus, despite increasing evidence of efficacy, the mechanisms underlying improvement, dose response, adverse effects, or even optimal ages for receiving CI therapy have not been delineated.[17]

Children possess far better brain reorganizational capabilities after lesions than adults (see refs 18–20 for examples). Such plasticity is assumed to be greater in younger children, because the central nervous system is still in the early stages of postnatal development. The neural substrates for hand control, however, continue to develop over the first 2 decades of life (see refs 21–23 for examples), which suggests the presence of neuroplasticity in older children as well. This notion is supported by findings that CI therapy is beneficial in older children and adolescents.[15,17,24] Recent findings suggest diminished outcome of language development for children who sustained a stroke at <1 year of age as opposed to children who sustained a stroke at a later age.[25] Furthermore, within a younger population of children with hemiplegia (aged 1.5–4 years), there was a relationship between age and improvement, with older children actually improving more than younger children in the extent to which they effectively use their involved hand during bimanual tasks.[14] Thus, a general "the-earlier-the-better" rule may not always be applicable. Should there be greater plasticity in younger children, its benefit may be countered by a reduced attention to task during structured practice. There may also be motivation differences between younger and older children. Younger children may be more extrinsically motivated (ie, by interventionists and parents) than older children, who may be more motivated to improve their own motor function given an increased awareness of their impairments and their desire for social inclusion with peers.

In the present study, we examine the relationship between efficacy of a child-friendly form of CI therapy[1] and age on involved upper-extremity function in children with hemiplegic CP who were aged 4 to 13 years. This age range was selected because (1) we have developed and tested a form of CI therapy designed to be child-friendly and appropriate for children >4 years of age,[1,26] and (2) standardized outcome measures exist that allow us to compare across all children ≥4 years of age. Specifically, we compared the efficacy in children aged 4 to 8 vs 9 to 13 years. This division (before and after 8 years) was selected, because coordination of fine finger force development during grasping approximates that of adults by the age of 8 years[27,28] (see ref 29) with more subtle development occurring until adolescence. Furthermore, studies using transcranial magnetic stimulation to examine relaxed central motor conduction time show that children reach adult-like patterns around the age of 10 years.[22,23,30,31] We selected outcome measures that would provide information at 3 levels: (1) movement efficiency and functional limitations (clinical-standardized and criterion-referenced tests of upper-extremity and hand function); (2) environmental functional limitations (caregiver report); and (3) impairment (clinical tests of sensibility, strength, and muscle tone).

METHODS

Participants and Recruitment

The inclusion criteria were established on the basis of those used in CI-therapy adult stroke studies[7] and prior studies with young children.[1,24,26] The criteria included (1) the ability to extend the wrist ≥20° and the metacarpophalangeal joint 10° from full flexion,[32] (2) a 50% difference between the involved and noninvolved hand on the Jebsen-Taylor Test of Hand Function,[33] (3) a score within 1 SD from the mean on the Kaufman Brief Intelligence Test,[34] and (4) willingness to agree to intervention and testing procedures and travel to the university for participation. Children were excluded who had (1) any health problems that are not associated with CP, (2) seizures, (3) visual problems that would prevent them from carrying out the intervention or testing tasks, (4) severe muscle tone (Modified Ashworth score of >3), (5) orthopedic surgery on their more affected upper extremity, (6) experienced a dorsal rhizotomy, (7) received botulinum toxin therapy in the upper-extremity musculature during the last 6 months or who wish to receive it within the period of study, (8) received intrathecal baclofen, and (9) balance problems while wearing the restraint.

After telephone and home screening, 19 children 4 to 8 years of age (designated "younger children") and 9 children 9 to 13 years of age (designated "older children") met the inclusion criteria and initially agreed to participate in the study. For the younger children, 2 of the 19 children withdrew before receiving the intervention because the study required too much commitment, and 1 child was removed from the intervention because the interventionists felt she was unable to tolerate the intervention. Three younger children were lost to follow-up because of failure to attend the posttest evaluation, and 1 child was excluded for failure to cooperate during testing. Thus, data from 12 children between the ages of 4 to 8 years (mean age: 6.7 years) were analyzed. For the older children, all but 1 child, who withdrew before participation because of other commitments, participated in the study. As a result, 8 children 9 to13 years of age (mean age: 11.4 years; see Table 1) participated. Two children, 1 in each age group, failed to participate in the 6-month posttest, although their data were still included. The data of some of the younger children were included as part of a randomized, controlled trial of CI therapy in 4- to 8-year-olds.[26] The study was approved by the Teachers College, Columbia University Institutional Review Board.

CI Therapy

The intervention (described in detail in refs 1,26) was provided on 10 of 12 consecutive days during summer or school vacations (typically 2 weeks of weekdays) at Teachers College, Columbia University, with groups of 2 to 4 children. Briefly, the children wore a cotton sling (Fig 1) on the noninvolved upper extremity for the entire intervention session (6 hours) that was removed at the end of each session. The sling was strapped to the child's trunk, and the distal end was sewn shut to prevent using the noninvolved hand. Time out of the sling during the 6-hour period was allowed only for designated activities (eg, toileting and hand washing) and could not exceed 30 minutes per day. At the end of each day, each child went home with an exercise program to practice with the involved upper extremity (without any restraint) for 1 hour during the evening. This home exercise program was extended to 2 hours per day for 6 months after the intervention, and parents completed activity logs to monitor compliance.

During each session, every child received individualized instruction from a trained interventionist involving the specific practice of designated target movements (see

TABLE 1 **Study Participants**

Child	Group	Involved Side	Gender	Age, y	Jebsen Pretest Score, s	TPD, mm	Muscle Tone S/E/W
1	Younger	L	F	7.4	720	NR	0/1/2
2	Younger	L	F	7.6	720	8	0/3/2
3	Younger	L	M	7.4	558	8	0/1/1
4	Younger	R	M	4.6	325	NR	0/1/0
5	Younger	L	F	7.6	322	8	1/1/1
6	Younger	L	F	5.9	285	11	0/1+/1
7	Younger	L	F	7.8	222	8	0/1/1
8	Younger	R	M	7.1	220	4	1/2/1+
9	Younger	R	F	6.6	208	5	1/1/1
10	Younger	L	M	7.9	205	7	1/1/1+
11	Younger	L	M	4.4	188	6	1/1/1
12	Younger	R	M	4.5	464	NR	1+/2/1
13	Older	R	M	10.66	541	7	0/1/1
14	Older	R	M	10.83	531	6	1/1+/1+
15	Older	R	F	11.5	213	5	1/1/1
16	Older	R	M	12.9	198	8	0/2/2
17	Older	R	F	12.66	175	6	1/1+/1
18	Older	R	M	10.58	170	6	1+/2/1+
19	Older	R	M	10.16	99	4	0/0/0
20	Older	L	F	12.1	43	3	1/0/0

L indicates left; R, right; TPD, 2-point discrimination; NR, not reliable; S, shoulder; E, elbow; W, wrist. Muscle tone determined by Modified Ashworth Scale (0–4). Subjects are listed in descending order based on Jebsen times at pretest.

FIGURE 1
A child with the sling. Note that the sling is sewn shut and secured snugly to the child's trunk with a strap to prevent use as an assist.

ref 1). Children were engaged in play and functional activities that provided 2 types of structured practice using the involved upper extremity, especially the hand. "Repetitive-task practice" involved performing a target movement in a functional context or in relation to other movements (eg, practicing forearm supination by turning over cards within the context of a game). "Shaping" involved practicing a target movement in isolation of other movements under a time constraint of 30 seconds (eg, turning over as many cards as possible within that time frame). As soon as the target movement was performed successfully, the difficulty of the task was increased by changing either temporal or spatial/accuracy task constraints. "Success" was defined as achieving either the same frequency in 3 of 5 trials (30 seconds each) or an increasing frequency in 3 of 5 consecutive 30-second trials. The choice of changing either spatial/accuracy or temporal dimensions depended on the constraints of a particular task and the target movements that were elicited by the task. Duration for completing each shaping task was timed with a stopwatch, and data were recorded on a daily data sheet by the interventionist.

Table 2 summarizes the types of activities used, with examples of targeted movements and how the constraints were graded to vary the difficulty. We established a list of 61 tasks across 7 categories. These tasks included functional tasks (eg, eating and putting away games), card games (eg, Old Maid and Uno), board games (eg, Candyland and Monopoly), manipulative games (eg, Don't Break the Ice and Battleship), puzzles, arts and crafts (eg, drawing and painting), and gross motor activities (bowling and Scatch). We viewed the choice of specific activities as less important than the movements that they elicited. None of the tasks tested in the outcome measures were practiced during the intervention. The target movements for both repetitive-task practice and shaping were recorded by the interventionist on a daily data sheet along with the description of the task and task duration. Total time spent performing task

TABLE 2 **CI Therapy Activities**

Activity Category	No. of Activities	Shaping	Repetitive-Task Practice	Movements Targeted	Graded Constraints
Functional tasks	11	4	8	Wrist extension, supination, and pronation	Supination and pronation: for turning key in lock, vary starting position of key to grade from using only supination to using both supination and pronation
Card games	6	6	6	Supination, precision grasp	Precision grasp: less difficult when cards are beveled on deck for easier grasp; increase difficulty by not beveling the cards
Board games	14	9	14	Supination, wrist extension, precision grasp, maintaining grasp through changes in spatial orientation	Active wrist extension: position deck of cards to elicit wrist extension and grade difficulty by changing position of deck
Gross motor	7	4	7	Shoulder flexion, shoulder abduction, shoulder external rotation, wrist extension	Shoulder flexion: elicit shoulder flexion by moving child from easier position stabilized against a wall to free standing position that requires more control
Manipulative games	21	14	21	Finger individuation, precision grasp, wrist extension, modifying grasp to accommodate various objects	Precision grasp: to increase difficulty provide child with increasingly smaller or more complex objects to manipulate
Puzzles	2	0	2	In-hand manipulation, precision grasp, release accuracy	Release accuracy: once competency in releasing puzzle pieces is attained, increase difficulty by introducing a puzzle with smaller pieces
Arts and crafts	2	0	2	Supination, precision grasp, maintaining grasp through changes in spatial orientation	Maintaining grasp: begin child at an easier level with a built-up brush and increase difficulty by removing assist; smaller brushes can be introduced

activities, as well as the percentage of time spent in shaping and repetitive-task practice, were calculated as a measure of dosing. Children were verbally provided positive reinforcement throughout a task for performance of target movements. At the end of each session, the interventionists and supervisor attended a "team meeting" to discuss progress of each child, problem solve, and plan for the next day.

Measurement

Outcome measures were selected that would provide information at 3 levels. To assess upper-extremity efficiency, the Jebsen-Taylor Test of Hand Function[35] was performed, and this measure served as the primary outcome measure. The test was modified by capping the maximum allowable time to complete each of the 6 timed items (writing was excluded) at 2 minutes instead of 3 minutes to reduce frustration levels associated with failure to accomplish the task. Thus, the maximum time to complete all of the items was 720 seconds. We also used subtest 8 (speed and dexterity) of the Bruininks-Oseretsky Test of Motor Proficiency, which consisted of both unimanual and bimanual items (unimanual items performed with the involved extremity).[36] Both tests were videotaped for additional analyses. At the environmental level, a Caregiver Functional Use Survey (CFUS; see ref 26) was designed to assess caregivers' perceptions of how much and how well their child used their involved upper extremity. Fourteen bimanual items were rated on a 6-point Likert scale on the frequency and quality of hand use. The following tests were used for measurement at the impairment level: 2-point discrimination[37]; hand-grip strength using a hand-held dynamometer[38]; and muscle tone at the shoulder, elbow, and wrist using the Modified Ashworth scale.[39]

Each participant was evaluated once before (pretest) and 3 times after the intervention. All of the evaluations took place in the Movement Sciences Laboratories at Teachers College, Columbia University. The same evaluator performed all testing of a specific child. A total of 5 evaluators were used over the course of this study. Each evaluator received 20 hours of training to assure consistency and establish reliability. The evaluators are staff members who, in the course of their jobs, routinely evaluate children participating in a number of randomized, controlled trials in our laboratory. All of the interventions took place on different floors from evaluation, and staff members were not told in which study a given individual was participating. Thus, they were blinded to the fact that the children received any treatment, and all of the blinding was maintained successfully throughout the study period. Intrarater and interrater reliability were measured (Jebsen-Taylor Test: intrarater reliability, 0.99; interrater reliability, 0.99; Bruininks-Oseretsky Test: intrarater reliability, 1.0; interrater reliability, 0.94).

For all of the testing sessions and for measures of movement efficiency and impairment, children were seated comfortably 10 cm behind an adjustable table.

The CFUS was administered to the child's caregiver after the administration of these tests.

Statistical Analysis

A 2-group (younger versus older) × 4-session (pretest versus posttests) analysis-of-variance repeated-measures design with the repeated measure on the second factor was used to evaluate differences for each measure. Because 2 children were missing from the 6-month posttest, for comparison, the statistical tests were also performed on all of the children through the 1-month posttest to ensure that the missing data did not influence our results. An overall group by testing-session interaction tested whether the average time course differed between the age groups. This approach effectively controls for differences at baseline between the 2 groups. Tests of simple effects were used when appropriate. The tests were also performed on the data after log transformation to determine if the distribution of data influenced the results. The results were qualitatively similar in all of the cases; thus, we report only the complete data set through 6 months on nontransformed data.

To determine factors that might influence changes in motor performance, hand severity, children's behavior (number of redirections) during the evaluation sessions, and age were regressed against normalized (%) changes in the Jebsen-Taylor Test scores from the pretest to the posttest (because the baseline values differed among the children). Behavior was determined through a review of videotapes (without sound) of each testing session. The Jebsen-Taylor test score taken during the screening was used as a measure of severity. Three evaluators reviewed these videotapes and, as a group, categorized and defined those behaviors (disruptive, noncompliant, or inattentive) exhibited on the videotapes that resulted in redirecting a child on a test item. An evaluator who was blinded to the order of the testing session and did not know the children recorded the number of disruptive, noncompliant, and inattentive behaviors (based on the definitions generated by the group described above) that were displayed by each child during an evaluation session. The frequency of these behaviors was used as a predictor of how well a child attended to the task throughout the intervention. A separate regression analysis was used to determine the relationship among practice intensity, behavior during the intervention session, and severity of hand function to normalized (%) changes in the Jebsen-Taylor Test of Hand Function from the preintervention testing session to the 1-week postintervention testing session for each age group. Practice intensity was determined by the sum of the time on task data for each child during the intervention period and the time that each child spent on practice at home during the intervention. The Jebsen-Taylor Test of Hand Function score obtained during screening (which was not significantly different from the pretest score) was used as a measure of severity of involved hand function. All of the tests were conducted at the $P < .05$ level.

RESULTS

The intervention required that children wear their restraints and participate in activities for a total of 60 hours. Because of transitioning between activities, toileting, and time spent by the interventionists in redirecting and reinforcing the children's time on task, children spent considerably less time performing activities. Overall, the younger children spent an average of 35 hours (range: 20–50 hours) or 58% of the time during the intervention in structured practice. Of this time, 33% was spent in shaping practice, and 67% was spent in repetitive-task practice. The older children spent an average of 36 hours (range: 26–44 hours) or 60% of the time during the intervention in structured practice. Of this time, 35% was spent in shaping practice, and 65% was spent in repetitive-task practice. None of the children were out of their sling for >15 minutes during a 6-hour intervention day. In addition, the younger children used their involved upper extremity in home practice, on average, 5.7 hours per 10 days during the intervention practicing and 7.3 hours per week for 6 months after the intervention. The older children used their involved upper extremity in home practice, on average, 5.5 hours per 10 days during the intervention practicing and 6.35 hours per week for 6 months after the intervention.

Movement Efficiency

To determine whether performing the tests alone with short durations between them would result in improvements, we compared the scores for the Jebsen-Taylor Test of Hand Function taken during the eligibility screening with that of the pretest (typically, these tests were administered within 1 month of each other), thus establishing a longer baseline. For the younger children, the mean screening score was 373 seconds, and the mean pretest score was 370 seconds ($P > .05$). For the older children, the mean screening score was 247 seconds, and the pretest score was 246 seconds ($P > .05$). This level of consistency indicates that all of the children had stable baselines before participating.

As shown in Fig 2, the younger children were slower than the older children on the Jebsen-Taylor Test at all of the testing sessions (but group effect was $P > .05$). Although children in both groups improved from pretest to posttest (main effect, $F_{3,48} = 11.8$; $P = .01$; effect size $[\eta^2] = 0.425$), there was no age × testing-session interaction, which indicated that there was no difference in the rate of improvement ($P > .05$). Posthoc analysis indicates that the change occurred from the pretest to the 1-week posttest, with no significant differences in scores from the 1-week posttest to 6-month posttest ($P > .05$).

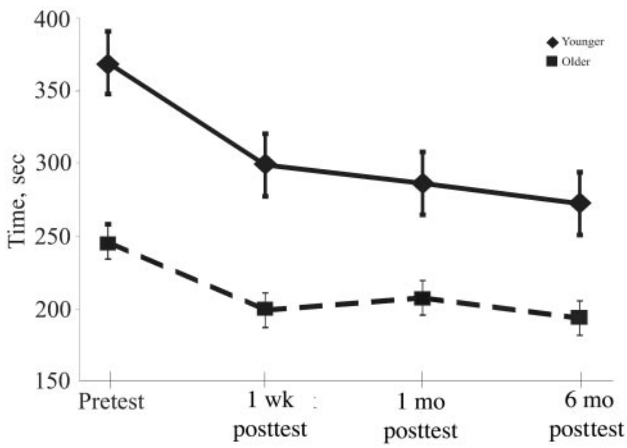

FIGURE 2
Mean ± SEM time to complete the 6 timed items (writing excluded) of the Jebsen-Taylor Test of Hand Function for the younger (solid line; $n = 12$) and older (dashed line; $n = 8$) age groups at each testing session. Faster times correspond with better performance. The maximum allowable time to complete each item was capped at 120 seconds, resulting in a maximum score of 720 seconds.

The younger children had worse scores than the older children on the Bruininks-Oseretsky Test of Motor Proficiency at all of the testing sessions (but group effect was $P > .05$). Although children in both groups improved (main effect, $F_{3,48} = 10.98$; $P = .01$; $\eta^2 = 0.407$), there was no age × testing-session interaction, which indicates that there was no difference in the rate of improvement ($P > .05$; Fig 3). Again, the change occurred between the pretest and 1-week posttest, with children in both groups maintaining these changes from the posttest through the 6-month follow-up ($P > .05$).

Environmental Level

Parents of children in both age groups perceived improvement (main effect, $F_{3,48} = 9.52$; $P < .01$; $\eta^2 = 0.373$) from pretest to posttest in the frequency of use of the involved hand and arm (Fig 4A). Caregivers of children in both age groups also noted a change in quality of movement (main effect, $F_{3,48} = 15.58$; $P = .01$; $\eta^2 = 0.493$) but, again, no difference in improvement between age groups ($P > .05$; Fig 4B). There was no group difference or group × testing-session interaction for either measure.

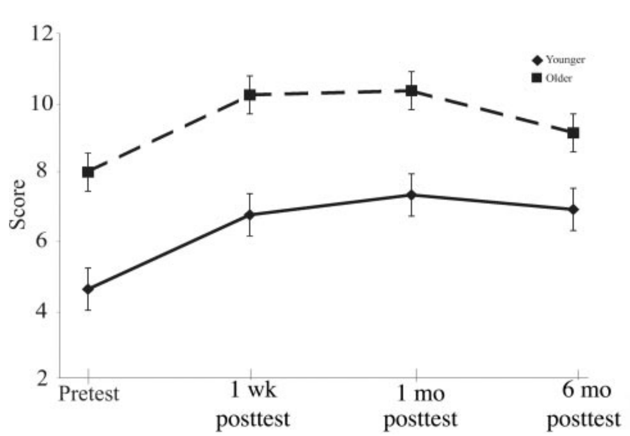

FIGURE 3
Mean ± SEM score on the Bruininks-Oseretsky Test of Motor Proficiency (subtest 8) for the younger (solid line; $n = 12$) and older (dashed line; $n = 8$) age groups at each testing session. Higher scores correspond with better performance.

Other Clinical Tests

Scores for 2-point discrimination, hand-grip strength, and the Ashworth scale were not statistically different across any of the testing sessions ($P > .05$ in all cases) for either age group.

Predictors of Increased Movement Efficiency

Overall, none of the factors (age, children's behavior, or hand severity) individually related to change in performance. However, the number of redirections and age combined explained 38.5% of the variance ($P < .05$), primarily because the number of redirections was higher in younger children (mean: 8 redirections per session) than in older children (mean: 1.3 per session; $r = -0.563$; $P < .005$ between age and number of redirections). Severity was also correlated with number of redirections ($r = 0.373$; $P < .053$). In the younger group, both hand severity and the children's behavior were significantly related to changes in performance ($P < .01$) and accounted for 84.2% of the variance. In contrast, none of the factors were related to change in performance from pretest to 1-week posttest ($P > .05$) in the older group.

Efficacy in Right Versus Left Hemiplegia

To determine whether our results may have been influenced by the uneven distribution of right and left involvement within each age group (ie, younger children had predominantly left-side involvement, whereas older children had predominantly right-side involvement), we collapsed data across the 2 age groups and compared the pretest and 1-week posttest data of children with right versus left hemiplegia. Overall, we found no interaction of side of involvement and testing session for any measure ($P > .05$ in all cases).

DISCUSSION

The results are in agreement with other studies suggesting that CI therapy improves involved hand-movement efficiency and environmental functional limitations in children with hemiplegia. Furthermore, they concur with studies suggesting that it may benefit even older children and adolescents. This concurrence is important, because strong evidence for efficacy of any other treatment options, including physical therapy, occupational therapy, conductive education, neurodevelopmental therapy, peripheral splinting/casting, and pharmacotherapy (eg, botulinum toxin type A) is lacking.[40] Nevertheless, we did not find any difference in efficacy for

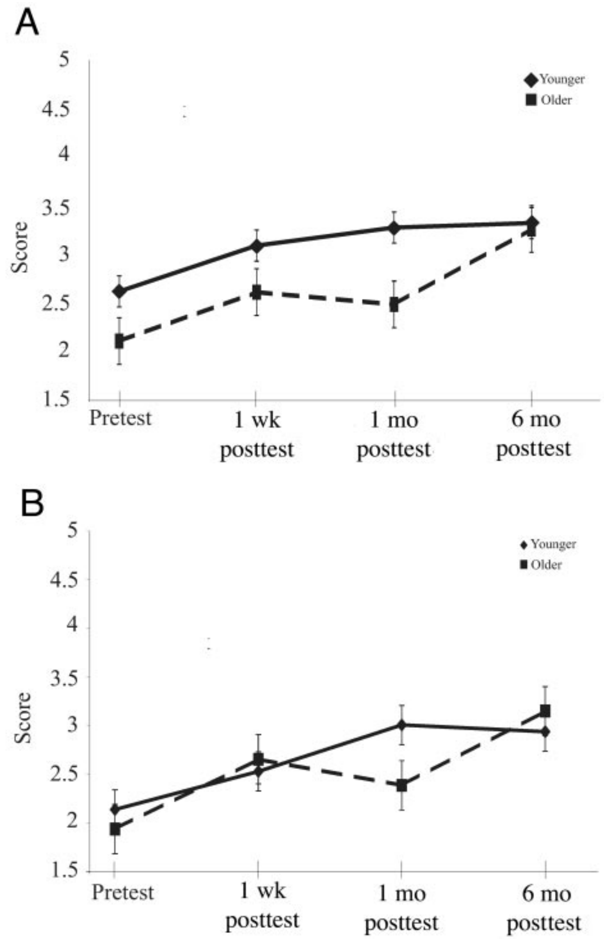

FIGURE 4
Mean ± SEM score on the CFUS for the younger (solid line; $n = 12$) and older (dashed line; $n = 8$) age groups at each testing session. A, Frequency of use. B, Quality of movement. Scores represent average ratings on 14 bimanual items from zero (never used) to 5 (used as frequently or as well as the noninvolved hand). Higher scores correspond with increased quality and quantity of involved extremity use.

younger and older children. These findings, as well as important considerations and clinical implications, are discussed below.

Optimal Age for CI Therapy

To date, the efficacy of CI therapy and forced use has been investigated in participants as young as 7 months[41] and as old as 18 years[15] (reviewed in ref 16). Because of the varying methodologies, durations, and testing measures used in studies of CI therapy and forced use to date, comparing efficacy across ages has not been possible (see ref 16). This study represents one of the most comprehensive investigations of CI therapy in children with hemiplegia to date. Efficacy was examined at the environmental, movement-efficiency, and impairment levels across a wide range of ages. The results suggest that the intensive practice associated with CI therapy can improve movement efficiency and environmental functional limitations in a carefully selected subgroup of children with hemiplegic CP of a variety of ages.

The results, at face value, suggest that efficacy is not age-dependent. We did not find any differences in efficacy between the younger and older children. The total time spent with the interventionists practicing using the involved hands did not differ between the 2 groups. However, several important factors need to be taken into consideration. Despite spending approximately the same time engaged in tasks, the actual amount of time moving, which we were unable to measure directly, may have differed. For example, the number of redirections during testing sessions, perhaps a surrogate of attention during the intervention, was 6 times higher in the younger children and suggests that younger children may have needed more “prodding” to attend to task. Interventionists nearly always reported having more motivation problems in the younger children at our team meeting. Older children often had specific goals and appeared to work harder at achieving them. Thus, the same gains achieved by the older children may conceivably require more work. This is supported by the fact that gains in younger children may be observed using forced use, without structured intensive practice (eg, see ref 42) or CI therapy modified to be even less intense.[14] The format of the intervention in this study and others on older children (≥2 weeks of intensive structured practice)[1,12,15,24,26] is more synonymous with that used in studies of adult stroke patients.[7] Thus, whether older children would improve with reduced intensity associated with a few hours per week or forced use without structured practice is unknown. It is conceivable that providing the intervention multiple times during different stages of development would be beneficial, although this approach has not been tested.

Another factor that may affect our results is the ability to capture a child’s true performance capability. The substantially greater number of redirections for younger children during testing may suggest that we did not capture a child’s best possible motor performance, because performance may be related to his/her ability to attend to the test items. Thus, to directly compare the results across age groups may not be possible. On the other hand, on average, the older children had lower (albeit nonsignificantly) Jebsen scores, so they may have had reduced opportunity for improvement (floor effect). Furthermore, the results of the present study and our prior work[26] suggest that severity may be a predictor of improvement. However, directly comparing severity across age groups is not possible, because there are no accepted uniform definitions of severity. All of the children in the present study met the strict inclusion criteria, which were meant to eliminate children whose hand function was too mild or too severe. Although there are norm values for the Jebsen-Taylor test, all of the participants in the present study fall beyond the normed range. Although little is known about whether hand function develops in children with hemiplegia, there is some recent evidence indicating that this function may improve slightly during development.[43,44] Thus, there is no reason to believe that the younger children actually were afflicted more severely with CP. Furthermore, the relationship between severity and improvement only seems to hold true for younger rather than older children.

The results also suggest that despite the fact that older children may be more intrinsically motivated, whereas younger children may be more motivated by parents and interventionists, children in both groups improved. Because the number of redirections and age combined to explain 38.5% of the variance in improvement, motivation and concentration may be important. Severity was also a factor, because it was correlated with the number of redirections. It is likely that the more severe the involved hand, the more frustrating the experience, which can lead to reduced attention or more disruptive behavior during testing (and perhaps during the intervention). This may be more important for younger children who are not intrinsically motivated.

Practice Makes Better

The key element of CI therapy as applied in this study is practice. To engage children in an active intervention and sustain their attention, we established a list of fine motor and manipulative gross motor activities that elicit the general movement behaviors of interest.[1] They included a range of functional and play activities in which children might typically participate on a given day. The activities are age-appropriate and are all performed unimanually. Specific activities are selected by considering (1) joint movements with pronounced deficits, (2) joint movements that interventionists believe have the greatest potential of improving, and (3) child preference for activities that have similar potential for improving identified movements. The task is made progressively more difficult as the child improves in performance by requiring greater speed or accuracy, increased movement repetition, or performance-sensitive adaptations. We adapt the task constraints to allow success and remove them as the skill improves.

The tasks are less important than the movements they elicit. Thus, board games might be used for each age group (Candyland for younger children and Monopoly for older children). Although the actual games may differ between the 2 age groups, the movements elicited did not. The games in both cases could be used to encourage wrist supination and extension, precision grasp, and grasp maintenance (see Table 2).

The key ingredients of practice for optimal improvement are not known at this time. We used repetitive-task practice and shaping. Repetitive-task practice involves the performance of movements embedded in functional and play activities continuously for 15 to 20 minutes. This approach allows practice of a movement in the context of the preceding and following movement and a functional task. The environment can be manipulated to vary the task requirements, elicit specific movements, or grade the difficulty. Tasks are always monitored and adjusted so that frequent successes can be achieved. Shaping involves a motor task goal being approached in small steps by successive approximation and/or grading of the task difficulty based on the patient's capabilities and is similar to adaptive or part practice documented in the motor learning literature. Although both age groups spent approximately two thirds of the time in repetitive-task practice, the optimal ratio is not known. Animal studies have shown that the progression of difficulty may be particularly important, because limb use alone may not result in motor-map reorganization.[45] Furthermore, such brain reorganization and synapse formation may represent the consolidation of motor skill that occurs during the late stages of motor learning (eg, see ref 46).

The change in performance in both groups may represent developmental changes over the testing period or the effect of practice associated with taking the test multiple times over the study duration. However, these possibilities are unlikely for 2 reasons. First, the changes that occurred on the Jebsen test were seen exclusively between the pretest and 1-week posttest. Development would not be evident in such a short (3-week) period. Second, there were no differences between the screening scores and the pretest scores. The consistency indicates that children had stable baselines before participating. Thus, the changes we observed can likely be attributed to participating in the intervention.

An interesting finding for both age groups is that the intensive unimanual training led to improvements in both unimanual performance (Jebsen-Taylor Test) and bimanual tasks (CFUS and portions of the Bruininks). We do not expect that children with hemiplegia would continue to perform the unimanual activities practiced during the intervention once the restraint is removed. Increases in the amount and quality of bimanual performance during everyday activities of daily living, therefore, are perhaps even more important. From our perspective, an increase in the quality of life would mean better use of the involved extremity as an assist (eg, stabilizing an object while the noninvolved hand manipulates it). Thus, an obvious question is whether such gains would be better achieved by practicing with both hands. This topic is the focus of our future research.

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