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Abstract

To determine efficacy of pediatric Constraint-Induced Movement therapy, 20 children with congenital hemiparesis (ages 2 to 6 years) were randomly assigned to receive the treatment or usual care. Controls crossed over to the therapy after 6 months. Children receiving the therapy first exhibited emergence of more new classes of motor patterns and skills (eg, crawling, thumb-forefinger prehension; 6.4 vs 0.02, $P < .0001$, effect size $d = 1.3$), and demonstrated significant gains in spontaneous use of the more affected arm at home (2.2 vs 0.1, $P < .0001$, $d = 3.8$) and in a laboratory motor function test. Depending on the measure, benefits were maintained (range, no loss to 68% retention over 6 months). When controls crossed over to the therapy, they exhibited improvements as great as or greater than those receiving therapy first. Thus, Constraint-Induced Movement therapy appears to be efficacious for young children with hemiparesis consequent to congenital stroke.

Keywords

Constraint-Induced Movement therapy, cerebral palsy, hemiparesis, constraint-induced therapy, rehabilitation, upper extremity

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Cerebral palsy is defined as a group of nonprogressive disorders of movement caused by a lesion or other defect in the developing brain.¹ The general category consists of several syndromes with differing symptoms and etiologies. Motor impairment that is greater on one side of the body than the other may be characterized as asymmetric cerebral palsy and constitutes at least one third of cases. A large subtype within this category consists of children with motor deficit resulting from stroke in the prenatal, perinatal, or very early antenatal period.^{2,3} A number of physical rehabilitation approaches have been used with cerebral palsy; however, there are considerable questions in the literature as to their efficacy.⁴⁻¹⁰

A family of neurorehabilitation techniques termed Constraint-Induced Movement therapy has been developed in this laboratory over the past 25 years. The technique was derived from basic research with adult and infant monkeys.^{11,12} Translation of the technique to humans began with application to the upper extremity of adult chronic stroke patients.¹³ Efficacy in substantially reducing the motor deficit in these patients was demonstrated in 2 randomized placebo-controlled trials,^{13,14} a multisite randomized controlled trial,¹⁵ and several replications.¹⁶⁻¹⁹ Equivalent results have been obtained with adult patients after traumatic brain injury,²⁰ brain resection, and for the lower extremity,²¹ and

most recently with multiple sclerosis.^{22,23} Approximately 300 papers using variants of Constraint-Induced Movement therapy with adults have been published reporting positive results. The treatment has been shown to result in large plastic changes in the organization and function of the brain²⁴⁻²⁶ that correlate with the clinical changes it produces.

In 1995 it was suggested that Constraint-Induced Movement therapy was potentially efficacious for children with cerebral palsy given the great plasticity of their central nervous systems.²⁷ The first experiment with a pediatric population was carried out

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with the upper extremity of children ages 8 months to 8 years who had asymmetric cerebral palsy stemming from a variety of causes.^{28,29} The results were at least as good as in adult patients with neurological damage. However, it was thought that varying etiologies might give rise to a large variance in results that might mask the true magnitude of the treatment effect. The present study, which sought to determine efficacy of pediatric Constraint-Induced Movement therapy, was therefore undertaken with a more narrowly defined subtype of cerebral palsy, congenital hemiparesis consequent to stroke. It is a randomized, controlled trial with crossover of a usual and customary care control group to Constraint-Induced Movement therapy 6 months after initial enrollment.

Since the initial study from this laboratory²⁸ a number of other pediatric Constraint-Induced Movement therapy studies have been published.³⁰⁻⁵⁵ However, because of substantial differences in the age and homogeneity of the diagnostic categories of the subject sample, these studies do not provide an answer to the question addressed here.

Methods

Patients

Children who met inclusion criteria were recruited consecutively in the chronological order in which their parents contacted the project, on self-referral or referral by health care practitioners. Table 1 lists selected characteristics of the participants before treatment. There were no significant differences between the children in the 2 groups on these variables or on the study outcome measures at pretreatment testing shown in Table 2. Two children assigned to the control group dropped out before treatment began, 1 because of a seizure and 1 because of an indefinite hospitalization. Thus, at pretreatment testing there were 10 participants each in the immediate Constraint-Induced Movement therapy group and the usual and customary care control group, 9 of the latter were crossed over to Constraint-Induced Movement therapy after a 6-month delay (the tenth child dropped out before crossover because of financial difficulty in paying travel expenses that had not been anticipated at time of enrollment 6 months earlier).

Inclusion criteria were as follows: stroke in the prenatal, perinatal, or very early antenatal period confirmed by magnetic resonance images (MRIs) obtained from medical records or personal physicians; upper extremity hemiparesis; age 2 to 6 years; no serious or recurring medical complications; and living within 40 miles of the University of Alabama at Birmingham/Children's Hospital of Alabama, or willing to temporarily relocate to the Birmingham area for treatment. Exclusion criteria were as follows: too little deficit in real-world spontaneous use of the more affected upper extremity as indicated by a score of >2.5 on the Pediatric Motor Activity Log; uncontrolled seizures; botulinum toxin in the upper extremity or other spasticity medication within 3 months of pretreatment testing; no fixed contractures in the affected upper extremity that would limit activity engagement (ie, a 4 or greater on the Ashworth Scale at any joint); and previous Constraint-Induced Movement therapy or forced use therapy. Most children in this sample had mild to moderate motor deficits according to a system of grading based on active range of motion displayed in 20 commonly tested movements (see Appendix). No children were excluded because of severity of symptoms. The University of Alabama at Birmingham Institutional Review Board approved the study protocol and parents signed informed consent statements.

Table 1. Demographic and Cerebral Palsy-Related Characteristics of Participants^a

Characteristic	CI Therapy (n = 10)	Controls (n = 10)
Age, mean year \pm SD	4.0 \pm 1.2	3.3 \pm 1.6
Female, n (%)	8 (80)	8 (80)
Paresis of right side, n (%)	8 (80)	6 (60)
Severity of impairment, ^b n (%)		
Mild	3 (30)	5 (50)
Moderate	2 (20)	2 (20)
Moderately severe	3 (30)	2 (20) ^c
Severe	1 (10)	1 (10)
Very severe	1 (10)	0 (0)
History of seizures, n (%)	4 (40)	1 (10)
PT/OT at enrollment, hours per week (\pm SD)	0.6 \pm 0.5	1.0 \pm 0.9

Abbreviations: CI, Constraint-Induced; PT, physical therapy; OT, occupational therapy; SD, standard deviation.

^a There were no significant differences between the groups.

^b Actual range of motion criteria for classification of severity of impairment are given in Appendix A.

^c Both children in this category had reductions in their severity of impairment before being crossed over to Constraint-Induced Movement therapy. One child's impairment moved into the moderate category, while the other moved into the mild category.

Study Design

Children were assigned randomly in blocks of 4 to either a group receiving Constraint-Induced Movement therapy immediately or a group that was tested, received usual and customary care for 6 months, and was then crossed over to Constraint-Induced Movement therapy. Usual and customary care typically consisted of 1 or 2 hours of conventional physical or occupational therapy per week (see Table 1).

Treatment

The basic method has been described in detail elsewhere.^{28,29} In brief, use of the more affected arm was trained intensively for 6h/d for 15 consecutive weekdays by a behavioral procedure termed "shaping."^{56,57} Shaping is a procedure whereby the subject is required to improve performance, usually in small steps, at each iteration of a movement to obtain a reward (enthusiastic praise, encouraging exclamations, and other signs of approval by the therapist). There was no training on weekends as in the previous pediatric Constraint-Induced Movement therapy trial. Training was carried out in the context of play to maintain the child's interest and attention and also during numerous activities of daily living (eg, feeding, dressing).

The less-affected arm was restrained in a long arm cast for the entire period of treatment to counteract the usually overwhelmingly strong tendency to use the less-affected arm. It thereby promoted increased use of the more affected arm. The cast extended from the mid-upper arm to just beyond the fingertips. It was univalved and the integrity of the skin was checked every other day, but only the therapist was allowed to remove the cast. The cast was univalved using safety scissors rather than a cast saw, making the process much less aversive to the young participants than in our previous work. Casts were fully washable and while 1 dried, a second cast was used.

Table 2. More Impaired Arm Short-Term Outcomes for Immediate CI Therapy, Control, and Crossover CI Therapy Children^a

Test	Immediate CI Therapy (n = 10)				Controls (n = 10)				Between-Group Differences in Change				Crossover CI Therapy (n = 9) ^b				Within-Group Pre to Post Change	
	Pre	Post	Change	Pre	Post	Change	Pre	Post	Change	d ^c	P	Pre	Post	Change	d ^d	P ^e		
PMAL, 0-5 points	1.3 ± 0.6	3.5 ± 0.6	2.2 ± 0.5	1.3 ± 0.3	1.4 ± 0.5	0.1 ± 0.3	1.4 ± 0.3	1.4 ± 0.5	0.1 ± 0.3	3.8	< .0001	1.4 ± 0.4	3.5 ± 0.5	2.1 ± 0.4	5.9	< .0001		
INMAP, No.	29.5 ± 7.1	35.9 ± 6.2	6.4 ± 3.2	27.6 ± 6.6	27.8 ± 6.6	0.2 ± 0.4	27.6 ± 6.6	27.8 ± 6.6	0.2 ± 0.4	1.3	< .0001	29.2 ± 5.2	38.9 ± 3.7	9.7 ± 3.2	3.1	< .0001		
PAFT																		
Unilateral tasks, affected arm use, % ^f	11.9 ± 8.0	45.0 ± 32.6	33.1 ± 31.5	14.4 ± 12.2	15.0 ± 12.9	0.6 ± 16.5	14.4 ± 12.2	15.0 ± 12.9	0.6 ± 16.5	1.3	.01	11.8 ± 7.9	57.0 ± 29.5	45.1 ± 33.8	1.3	.004		
Functional Ability, 0-5 points	2.3 ± 0.4	2.6 ± 0.4	0.3 ± 0.1	2.2 ± 0.5	2.1 ± 0.6	-0.1 ± 0.3	2.2 ± 0.5	2.1 ± 0.6	-0.1 ± 0.3	1.0	.03	2.1 ± 0.5	2.5 ± 0.5	0.4 ± 0.1	2.7	< .0001		
Movements with a net increase in AROM, % ^g	-	-	71.1 ± 11.4	-	-	7.6 ± 9.1	-	-	7.6 ± 9.1	1.7	< .0001	-	-	52.0 ± 26.6	1.5	< .0001		

Abbreviations: AROM, active range of motion; CI, Constraint-Induced; INMAP, Inventory of New Motor Activity and Programs test; PAFT, Pediatric Arm Function test; PMAL, Pediatric Motor Activity Log; SD, standard deviation.

^a Values are mean points ± SD.

^b One child in the control group dropped out of the study before crossover because of scheduling conflicts and travel finances for the parents unanticipated at enrollment 6 months earlier.

^c Cohen *d* is a measure of effect size (small *d* = 0.2, medium *d* = 0.5, large *d* = 0.8). It indexes the magnitude of the difference between the treatment and control groups at posttreatment. For each outcome, it is the mean posttreatment value in the experimental group minus the corresponding value in the control group, all divided by the pooled standard deviation for these 2 scores.

^d Cohen *d* is a within-subjects measure of effect size. It is the mean treatment change divided by the standard deviation of the change. Small, medium, and large values of *d* are considered to be 0.14, 0.36, and 0.57, respectively.

^e *P* values are reported for repeated measures ANOVA models with a specific contrast testing whether postcrossover Constraint-Induced Movement therapy scores were different from trend in precrossover scores (ie, baseline 1, baseline 2, and 6-month follow-up).

^f Values are for affected arm use for unilateral tasks only. For bilateral tasks, percentage of use of the affected arm also increased significantly after Constraint-Induced Movement therapy when given immediately or after crossover, but the differences were smaller.

^g This measure is the net number of 20 commonly tested upper-extremity movements with a positive change in active range of motion as a percentage of the number of movements tested that were outside normal limits before treatment (ie, those that had the potential to improve). Because this measure is a change score, pre- and posttreatment, values are not reported. A between-group *t* test was used to evaluate whether the difference in this metric between the Immediate Constraint-Induced Movement therapy and control groups at posttreatment is statistically significant, and Cohen *d*, a between-group index of effect size, is used to indicate the magnitude of this difference.

Children adapted to the casts easily with complaints infrequently extending beyond the first day. The process of adaptation differed little from when a limb is casted because of a fractured bone.

A number of other techniques, termed the "transfer package," were used to induce transfer of therapeutic gains from the treatment period to usual life activities.

1. The treatment was carried out in the child's home to maximize the similarity between the conditions of training and the normal life situation. In addition, training was carried out on trips outside the home (eg, a petting zoo, a botanical garden, a fast food restaurant, preschool).
2. The caregiver was trained to carry out the shaping of movements.
3. A written list of training tasks was drawn up for the caregiver to carry out over the weekends; the caregiver kept a diary of what was actually done.
4. The Pediatric Motor Activity Log was administered to the caregiver daily to determine the amount and quality of use of the more affected upper extremity during the treatment period.
5. Problem solving was carried out with the caregiver to try to deal with and circumvent perceived barriers to the child's use of the arm in specific activities, which the therapist deemed the child was capable of. The monitoring (Pediatric Motor Activity Log) and problem-solving procedures have been shown to be particularly important in Constraint-Induced Movement therapy research with adult stroke patients.^{26,58}
6. At the beginning of the fourteenth day of treatment, the cast was removed and the child received training in using the more affected arm in bilateral activities for the final 2 days of treatment.
7. Written training instructions were given to the caregivers so that they could continue training after the end of formal treatment to maintain the therapy gains.
8. Preschool teachers and other significant individuals were enlisted by the caregiver or therapist to keep reminding the child to use the more affected arm in activities of daily living.
9. Monitoring of compliance by the caregivers with the instructed posttreatment protocol by a weekly phone call for the first month after treatment in which the Pediatric Motor Activity Log was administered and problem solving carried out. The latter has also been shown to be of substantial importance in research with adults (Taub, Uswatte, Bowman, McKay, Mark, unpublished data, 2006).

Measures

Outcome measures were divided into instruments that quantify spontaneous use of the more affected extremity in the life situation (Pediatric Motor Activity Log and Inventory of New Motor Activities and Programs Instrument), and a laboratory motor function test that measures use of the affected extremity when it is requested (Pediatric Arm Function Test). Constraint-Induced Movement therapy with either adults or children affects the 2 types of measures differentially, the effect on spontaneous real-world use being by far the greater.^{58,59} Impairment was also measured (active and passive range of motion, Modified Ashworth Scale).

Real-World Outcome Measures

Pediatric Motor Activity Log. The Pediatric Motor Activity Log is a reliable and valid scripted, structured interview^{28,29} (G. Uswatte, E. Taub, A. Griffin, L. Vogtle, A. Rowe, J. Barman, in manuscript) that

is administered to the mother/parent immediately before and after treatment, daily during treatment, weekly for the first month after treatment, and at each follow-up time point. The parent is asked to rate how well (How Well Scale) and how often (How Often Scale) the participant used the more impaired arm on 26 upper-extremity activities over a specified period (eg, last week, since the last time I saw you). Both scales have 6 steps (0-5). Only the How Well Scale scores are reported here, because the How Well Scale and How Often Scale provide redundant information (G. Uswatte, E. Taub, A. Griffin, L. Vogtle, A. Rowe, J. Barman, in manuscript). In this dataset, for example, the pre- to posttreatment gains on the 2 scales are highly correlated ($r = .83$, $P < .0001$). Test scores are the average of the item scores. A videotape depicting each level of performance of 8 of the Pediatric Motor Activity Log activities is shown on the pretreatment testing day to the caregiver to help establish a common frame of reference across caregivers and experiments in the laboratory. The Pediatric Motor Activity Log is adapted from the Adult Motor Activity Log, which also has an established reliability and validity.⁶⁰⁻⁶²

Inventory of New Motor Activities and Programs instrument. It is common during Constraint-Induced Movement therapy treatment for children to begin exhibiting behavior they had never performed before. The Inventory of New Motor Activities and Programs instrument permits systematic recording of the first appearance of major classes of motor patterns and functional activities in children. It is a revised version of the Emerging Behavior Scale.²⁸ Scoring is based on general observation of the child throughout the day in spontaneous activity, during treatment, and in test situations; it is not based on the administration of a specific test. For a behavior to be scored as present, it must have been observed by at least 2 sources, 1 of whom must be the therapist. The therapist videotapes the behavior for future reference. For a behavior to be considered present at pretreatment it needs to be observed by just 1 source, either a parent or a trained professional.

Motor Ability and Impairment Measures

Pediatric Arm Function Test. The Pediatric Arm Function Test is a reliable and valid (G. Uswatte, E. Taub, A. Rowe, L. Vogtle, A. Griffin, J. Barman, in manuscript) upper-extremity motor test that was conducted in the laboratory before and after treatment and at 6-month follow-up. It consists of 17 unilateral and 9 bilateral tasks. On the first administration of the test, children are not given any prompts about which arm to use to accomplish the tasks. On the second administration, tasks on which children did not use their more impaired arm are repeated and the children are specifically asked to use the more impaired arm. The entire test is videotaped, and masked trained observers score each task independently from the videotape using a 6-step Functional Ability Scale. The Functional Ability Scale is the average of scores on tasks attempted with the more impaired arm on the first administration and separately for tasks repeated on the second administration. The percentage of tasks on which the more affected upper extremity is used on the first test administration is recorded as a limb preference score.

Passive and active range of motion. Because it is impractical to use goniometers for the hands of young children, passive and active range of motion were rated on a 4-point scale for 20 commonly measured movements immediately before and after treatment. The pretreatment scores were used as the basis for characterizing the severity of the deficit (see Appendix). The Ashworth Scale was used to rate the tone present for each of these movements.

Data Analysis

The efficacy of Constraint-Induced Movement therapy was evaluated by comparing pre- to posttreatment changes in the immediate Constraint-Induced Movement therapy group to corresponding changes in the usual and customary care control group using mixed-model analysis of variance (ANOVA; Statistical Analysis Software 9.1). Repeated-measures ANOVAs tested retention of gains over follow-up and the effect of crossing control children over to Constraint-Induced Movement therapy after completion of their 6-month follow-up testing. Initial between-group differences were tested using ANOVAs and chi-square tests. Correlation analyses, with correction for multiple tests,⁶³ explored associations between pretreatment characteristics and outcomes at posttreatment and 6-month follow-up in immediate and crossover Constraint-Induced Movement therapy children combined. Effect sizes were indexed using Cohen d (large $d = .4$) for between-group comparisons and Cohen d' (large $d' = .57$) for within-group comparisons.⁶⁴ On the basis of prior studies, we hypothesized there would be in the 4 motor domains assessed after Constraint-Induced Movement therapy.^{14,28}

Results

Immediate Effects of Constraint-Induced Movement Therapy

Table 2 lists mean pre- and posttreatment scores and their standard deviation, effect size indices, and significance values. Children immediately after Constraint-Induced Movement therapy used their more impaired arm in daily life more frequently and with better dexterity than children immediately after usual and customary care. The immediate Constraint-Induced Movement therapy group had a very large increase on the Pediatric Motor Activity Log relative to the control group (2.2 vs 0.1, $P < .0001$, $d = 3.8$). Figure 1 indicates that gains on the Pediatric Motor Activity Log were equally large after the control group was crossed over to Constraint-Induced Movement therapy (mean pre- to posttherapy change = 2.1, $P < .0001$, $d' = 5.9$).

The Inventory of New Motor Activities and Programs results indicate that a substantial number of new motor patterns performed with the more impaired arm emerged during Constraint-Induced Movement therapy, but few or none emerged during usual and customary care. For the immediate Constraint-Induced Movement therapy group, 6.4 entirely new classes of motor behavior emerged during treatment; the controls had a gain of only 0.2 ($P < .0001$, $d = 1.3$). After the controls were crossed over to Constraint-Induced Movement therapy, gains on the Inventory of New Motor Activities and Programs were large (9.7, $P < .0001$, $d' = 3.1$).

On a laboratory motor function test, the immediate Constraint-Induced Movement therapy group, compared with the control group, showed large improvements in the amount of use of the more impaired arm. On the first administration of the Pediatric Arm Function Test when children could choose whether to use the more impaired arm, immediate Constraint-

Induced Movement therapy children had a large pre- to post-treatment increase in the percentage of tasks attempted with the more impaired arm (11.9%-45.0%), while controls had a small increase, going from 14.4% to 15.0% ($P = .01$, $d = 1.3$). After crossover to Constraint-Induced Movement therapy, the controls had a large increase (11.8%-57.0%, $P = .004$, $d' = 1.3$). On the Pediatric Arm Function Test Functional Ability Scale, which indicates quality of movement, immediate Constraint-Induced Movement therapy children had a 0.3-point increase, while controls had a 0.1-point decrease ($P = .03$, $d = 1.0$). After crossover to Constraint-Induced Movement therapy, the controls showed a large increase in quality of movement (0.4-point increase, $P < .0001$, $d' = 2.7$).

The immediate Constraint-Induced Movement therapy group also showed large gains in active range of motion compared with the control children. Children in the immediate Constraint-Induced Movement therapy group had net increases in active range of motion for 71% of commonly tested movements that were outside normal limits at pretesting; the corresponding value for the control group was 8% ($P < .0001$, $d = 1.7$). After crossover to Constraint-Induced Movement therapy, those in the control group showed an increase of 52% in such movements ($P < .0001$, $d' = 1.5$). These changed values in active range of motion after Constraint-Induced Movement therapy are larger than those observed in adults.

Long-Term Effects of Constraint-Induced Movement Therapy

At 6-month follow-up, children in the immediate Constraint-Induced Movement therapy group continued to show larger gains than those in the control group on all measures ($P < .05$ for all measures). Furthermore, there was no significant loss of gains from posttreatment to 6 months on the Inventory of New Motor Activities and Programs or the Pediatric Arm Function Test or in active range of motion in the immediate or crossover Constraint-Induced Movement therapy groups or at 1 year in the immediate group ($P > .09$ for all measures). Table 3 lists 6-month outcomes. Figure 1 shows outcomes on the Pediatric Motor Activity Log in the immediate Constraint-Induced Movement therapy group up to 1 year after treatment and crossover Constraint-Induced Movement therapy group up to 6 months afterward. The immediate Constraint-Induced Movement therapy group had a reduction in Pediatric Motor Activity Log scores from posttreatment to 6-month follow-up (-0.7 ± 0.6 , $P = .005$, $d' = -1.2$), as did the crossover Constraint-Induced Movement therapy group (-0.7 ± 0.6 , $P = .009$, $d' = -1.1$). At 1-year follow-up, the reduction in Pediatric Motor Activity Log scores from posttreatment in the immediate Constraint-Induced Movement therapy group was larger than at 6 months (-1.0 ± 0.8 , $P = .003$, $d' = -1.3$). The 1-year follow-up was not available for the crossover Constraint-Induced Movement therapy group. Nevertheless, both groups still had large Pediatric Motor Activity Log

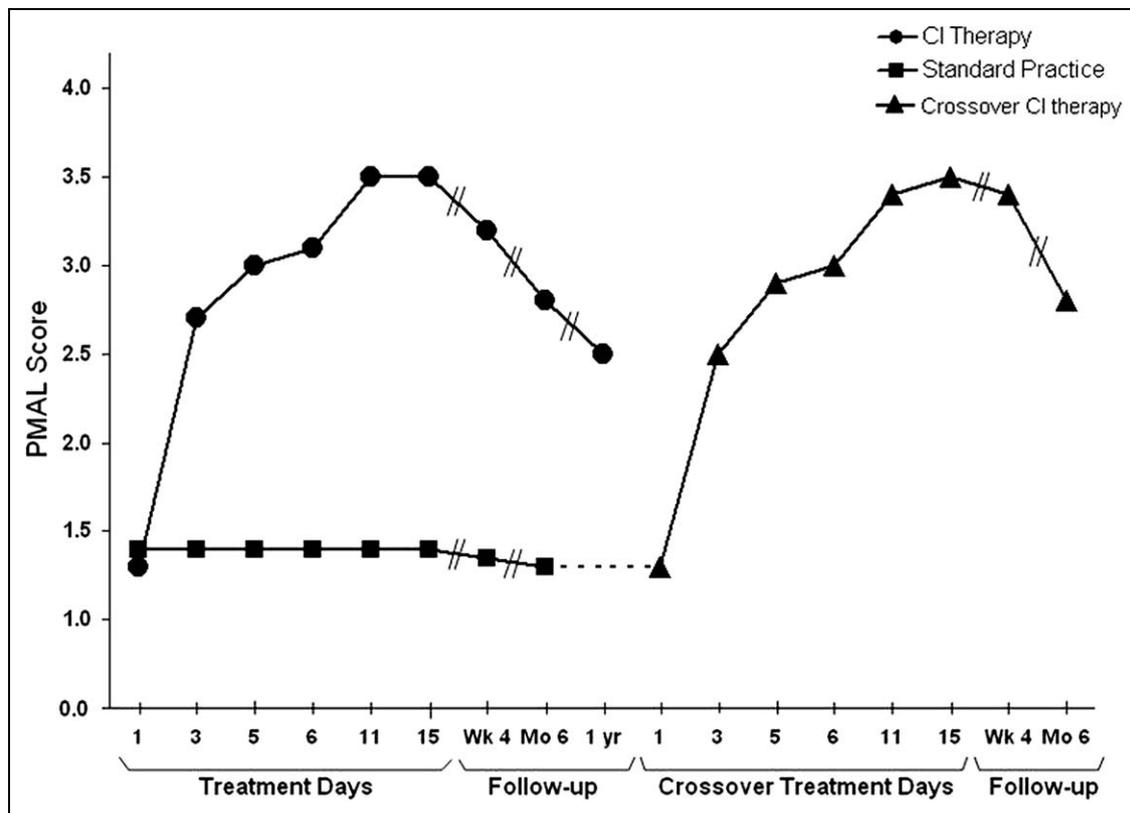


Figure 1. Spontaneous use of the more impaired arm (Pediatric Motor Activity Log score) for the immediate Constraint-Induced Movement therapy group and the control group before and after crossover to Constraint-Induced Movement therapy. Data for the immediate Constraint-Induced Movement therapy group are shown for treatment and 1, 6, and 12 months after treatment. Data for the control subjects are shown for 6 months after treatment, at which time they were crossed over to Constraint-Induced Movement therapy. After crossover data are shown for treatment and 1 and 6 months afterward.

gains from pretreatment at the end of follow-up ($P < .01$ for all measures, d' values > 1.2).

Relation of Pretreatment Characteristics to Constraint-Induced Movement Therapy Outcome

Immediately after Constraint-Induced Movement therapy, there were convergent statistical trends for children with mild motor deficits before treatment to have larger gains in general than children with severe deficits, and for girls to have larger gains than boys in the amount of spontaneous use of the more impaired arm. This is consistent with our findings with adults. Correlations between pretreatment severity of more affected arm motor impairment (see Appendix) and pre- to posttreatment gains on the Pediatric Motor Activity Log, Inventory of New Motor Activities and Programs, and Pediatric Arm Function Test scales ranged between $-.53$ and $-.69$ (range, $P = .025-.002$). Point-biserial correlations between female gender and gains on the Pediatric Motor Activity Log and Pediatric Arm Function Test Affected-Arm Use Scale were $.48$ ($P = .046$) and $.50$ ($P = .03$), respectively. There were also consistent trends for children with broad repertoires of motor patterns (ie, high Inventory

of New Motor Activities and Programs scores) before treatment to have large posttreatment gains on the Pediatric Motor Activity Log and Pediatric Arm Function Test scales (range, $r = .52-.61$; range, $P = .028-.007$). Retention of posttreatment gains at 6-month follow-up, however, was not correlated with any of these measures.

An additional posthoc analysis showed that children with parents who were cooperative with study procedures associated with the transfer package had large gains in real-world use of the more impaired arm after Constraint-Induced Movement therapy. Parent cooperativeness during treatment, as rated by project staff, had a large correlation with posttreatment Pediatric Motor Activity Log gains ($r = .62$, $P = .008$). The association between parent cooperativeness after treatment and retention of Pediatric Motor Activity Log gains at 6-month follow-up was similar ($r = .57$, $P = .026$).

Discussion

This trial involved a randomized, separate groups design with crossover of control participants 6 months after enrollment and testing. We found that pediatric Constraint-Induced Movement therapy produced substantial improvement in the paretic arm of

Table 3. Pre- to Posttreatment and Pretreatment to 6-month Follow-up Changes in the Immediate CI Therapy, Control, and Crossover CI Therapy Conditions^a

Test	Immediate CI Therapy		Controls		Crossover CI Therapy	
	Post	6 Month	Post	6 Month	Post	6 Month ^b
PMAL, 0-5 points	2.2 ± 0.5 ^c	1.5 ± 0.7 ^c	0.1 ± 0.3	0.1 ± 0.3	2.1 ± 0.4 ^d	1.5 ± 0.7 ^d
INMAP, No.	6.4 ± 3.2 ^c	6.6 ± 5.1 ^c	0.2 ± 0.4	1.6 ± 3.4	9.7 ± 3.2 ^d	9.5 ± 1.0 ^d
PAFT						
Unilateral tasks, affected arm use, % ^e	33.1 ± 31.5 ^c	22.2 ± 28.0 ^c	0.6 ± 16.5	-2.8 ± 13.7	45.1 ± 33.8 ^d	38.6 ± 34.3 ^d
Functional ability, 0-5 points	0.2 ± 0.1 ^c	0.2 ± 0.3 ^c	-0.1 ± 0.3	0.0 ± 0.3	0.4 ± 0.1 ^d	0.3 ± 0.2 ^d
Movements with a net increase in AROM, %	71.1 ± 11.4 ^c	70.6 ± 17.8 ^c	7.6 ± 9.1	55.0 ± 29.8	52.0 ± 26.6 ^d	58.1 ± 35.3 ^d

Abbreviations: AROM, active range of motion; CI, Constraint-Induced Movement; INMAP, Inventory of New Motor Activity and Programs test; PAFT, Pediatric Arm Function test; PMAL, Pediatric Motor Activity Log.

^a Values are mean points ± SD.

^b In the crossover Constraint-Induced Movement therapy group, data from 2 children at 6-month follow-up were substituted for by the mean score for the group at that testing session.

^c $P < .05$ for tests comparing either pre- to posttreatment or pre to 6-month follow-up changes in the immediate Constraint-Induced Movement therapy group to corresponding changes in the control group.

^d $P < .05$ for tests comparing either pre-treatment scores to posttreatment or 6-month follow-up scores in the crossover Constraint-Induced Movement therapy group.

^e Values are for affected arm use for unilateral tasks only. For bilateral tasks, change in percentage of use of the affected arm from posttreatment to 6 months after treatment was also not significant when Constraint-Induced Movement therapy was given immediately or after crossover.

young children with congenital hemiparesis consequent to stroke compared with children receiving usual and customary care. When the control children were crossed over to Constraint-Induced Movement therapy, they exhibited as large an improvement on all measures as the children receiving the treatment immediately. The treatment effect sizes were very large in most areas of motor functioning, particularly in spontaneous use of the affected arm in the life situation (Motor Activity Log scores). This is consistent with results for adults with neurological damage.

The effect sizes in this study are larger than in the previous study with children who have cerebral palsy with asymmetric motor deficits. In the previous study, children were treated for 21 consecutive days, whereas in this study they received treatment by a therapist only on the weekdays of 3 consecutive weeks (15 days), with instruction to the caregiver to frequently remind the child to use the more affected arm on weekends. Clearly, then, having a caregiver rather than a therapist carry out training on weekends did not reduce treatment outcome, and using the reduced protocol renders the therapy more in accord with the normal therapist work week and easier for clinical facilities to implement. A factor that could be responsible for the improved results in this experiment could be a more systematic and consistent focus on each element of the "transfer package," particularly on enlisting a parent as an adjunct therapist and making a weekly phone call to the parent for the first month after the end of formal treatment to administer the Pediatric Motor Activity Log, problem solve, and promote parent compliance with the posttreatment protocol. An alternate possibility is that working with a more coherent diagnostic category than previously used reduced the variance of the results and thereby increased the treatment effect size.

Another difference between the studies is the use of a cast material that permitted use of safety scissors to separate halves of the cast so that it was removable rather than a cast saw that was often aversive to the young participants.

Figure 1 and inspection of individual learning curves indicate that the largest part of the improvement in real-world use of the more impaired arm occurs in the first week of treatment and that gains tend to asymptote during the second or early part of the third week. This suggests the possible value of reducing the initial treatment period to 2 weeks and perhaps transferring the additional 5 days to a brush-up at the 6-month or 1-year time point to reverse the loss in retention of treatment effect at those times.

The effect sizes of the treatment changes on the Pediatric Arm Function Test, a laboratory motor function test, were $d = 1.3$ and 1.0 , which are large. However, the effect size of the treatment change on the Pediatric Motor Activity Log, a measure of the amount of spontaneous use of the more affected extremity in the life situation, was 3 to 3.5 times larger. The same is true for adults.^{58,59} This indicates that while Constraint-Induced Movement therapy produces a large improvement in the quality of movements made on request in the laboratory, it produces by far its largest effect on the degree to which a patient transfers the results of the therapeutic intervention from the clinic to the real world and uses an upper extremity in that setting without prompting. For persons with impaired extremities, these are 2 different domains of movement in both a pediatric population and in adults; to obtain a veridical picture of the effects of a rehabilitation therapy, it is necessary to measure both. The real-world effect is, of course, the more important result and it can be measured reliably and validly⁶⁰⁻⁶² (G. Uswatte, E. Taub, A. Griffin, L. Vogtle, A. Rowe, J. Barman, in

manuscript) by use of the Pediatric Motor Activity Log, using the procedure described in its administration manual (available on request). The reason for this dissociation between these 2 domains of movement in patients with impaired extremities has to do with the development of “learned nonuse”^{11,12,58} in adults or the closely related “developmental disregard” in persons with motor deficits that are present since birth or that develop within the first months of postnatal life.^{28,29} Constraint-Induced Movement therapy is particularly effective in overcoming learned non-use and developmental disregard.

A number of studies have been reported in the literature in which Constraint-Induced Movement therapy-like protocols have been used with young persons.³⁰⁻⁵⁵ All report positive results, but it is difficult to compare these studies with the present one quantitatively because a large number of the studies are case histories with only 1 to 3 subjects^{30-35,37,47,49,51,54} and a number involve adolescent or tween rather than pediatric subjects.^{31,34,38,45,49} In addition, those with appropriate sample sizes depart substantially from the protocol described here.^{36,41,43-46,55} Just 2 studies used a measure of the actual amount of spontaneous use of the more affected extremity in the life situation,^{39,44} which, as noted above, is by far the most important measure of rehabilitation treatment efficacy and which can diverge substantially from the results of a laboratory test, where the movements, including simulated activities of daily living, are requested by an investigator. The test used was the Caregiver Functional Use Survey, an instrument similar to and derived from to the Pediatric Motor Activity Log.

However, in one of these studies⁴⁵ the mean age of the subjects was 10 years. Tweens constitute a population whose characteristics for the purpose of Constraint-Induced Movement therapy are at least as close to those of adults as to the young children in this experiment, and require comparison to individuals in their own age range. The remaining study⁴⁴ used a modified form of Constraint-Induced Movement therapy termed “child-friendly” in 4- to 8-year-old children involving a day camp setting with restraint of the less affected arm for just 6 hours/day. The interaction between subject and therapist is characterized as “individualized” but no information is given on the duration or intensity of the interaction. The effect size of the treatment on the real-world measure at posttreatment is significant and in 1 study large, but it is 5% to 30.3% as large as the effect size of the real-world treatment effect obtained in this experiment, presumably as a result of the reduced treatment intensity employed.

It should be noted that pediatric Constraint-Induced Movement therapy is not a “cure” for motor deficit in children with cerebral palsy. It does not make movement normal nor is that its objective. It is important to make this clear to parents of participating children to avoid disappointment with a good result. The objective is to produce a substantial improvement in movement, and by a quantitative measure of what constitutes substantial improvement,^{62,65} each of the children in this trial met this objective.

Appendix A

Grading System for Severity of More-Impaired Arm Motor Deficit in Children With Cerebral Palsy^a

Grade of Deficit	Joint				
	Shoulder	Elbow	Wrist	Fingers	Thumb
2 (mild/moderate)	WNL/mild limitation ^b in flexion or abduction	WNL/mild limitation in extension	WNL/mild limitation in extension	WNL/mild limitation in extension	WNL/mild limitation in lateral abduction
3 (moderate)	Moderate limitation ^c in flexion or abduction	Moderate limitation in extension	Moderate limitation in extension	Moderate limitation in extension	Moderate limitation in lateral abduction
4 (moderately severe)	Severe limitation ^d in flexion or abduction, but >30°	Severe limitation in extension	Severe limitation in extension	Severe limitation in extension	Severe limitation in lateral abduction
5A (severe)	≤30° flexion or abduction	Initiation of flexion or extension	Initiation of wrist, fingers, or thumb movement		
5B (very severe)	≤30° flexion or abduction	Initiation of flexion or extension	No initiation of wrist, fingers, and thumb movement		

Abbreviations: WNL, within normal limits.

^a Movements described are minimum motor criteria (i.e., if a child does not meet the active range of motion criteria listed for the grade at even 1 joint, he or she would be placed in the grade corresponding to the movement present at the worst joint.)

^b Active range of motion is >2/3 to just below normal range.

^c Active range of motion is between 1/2 and 2/3 of normal range.

^d Active range of motion is <1/2 of normal range but movement but can be initiated.

Appendix B

Two Still Photographs From Video Demonstrating Effect of Constraint-Induced Therapy



Figure A. Top panel shows preconstraint-induced therapy self-feeding with a spoon. Limitations are weak grasp, no active wrist extension, needs assistance to pick up spoon and lift it to mouth, and unable to turn wrist to get food in mouth.



Figure B. Bottom panel shows postconstraint-induced therapy self-feeding with a spoon. Changes are successful on first attempt, improved wrist extension, independent in grasping spoon and bringing it to mouth, and improved trunk stability.

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Author Contributions

ET designed experiment, supervised work, wrote first draft of article. AG participated in experiment planning and data interpretation, supervised therapists on a day-to-day basis, tested patients. GU performed data collection and analysis, revised first draft of paper, and participated in data interpretation. KG treated half the patients, tested patients, and performed clinical evaluation of patient progress. JN treated half the patients, tested patients, and performed clinical evaluation of patient progress. CRL was medical director of project, performed medical evaluation of patients, and participated in data interpretation.

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Ethical Approval

The University of Alabama at Birmingham Institutional Review Board approved the study protocol and parents signed informed consent statements.

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