Published in final edited form as:

J Child Neurol. 2011 September ; 26(9): 1163–1173. doi:10.1177/0883073811408423.

Treatment of Congenital Hemiparesis with Pediatric Constraint-Induced Movement Therapy

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Abstract

To determine efficacy of pediatric constraint-induced therapy, 20 children with congenital hemiparesis (age, 2 to 6 years) were randomly assigned to receive the treatment or usual and customary care. Controls crossed over to constraint-induced therapy after 6 months. Children receiving the therapy first exhibited emergence of more new classes of motor patterns and skills (e.g., crawling, thumb-forefinger prehension; 6.4 vs. .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 constraint-induced therapy, they exhibited improvements as great or greater than those receiving therapy first. Thus, constraint-induced therapy appears to be efficacious for young children with hemiparesis consequent to congenital stroke.

Keywords

pediatric constraint-induced therapy; cerebral palsy; hemiparesis; constraint-induced therapy; pediatric rehabilitation; upper extremity

Introduction

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

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Presented at the Neurobiology of Disease in Children Symposium: Cerebrovascular Disease, in conjunction with the 39th Annual Meeting of the Child Neurology Society, Providence, Rhode Island, October 13, 2010. Supported by grants from the National Institutes of Health (5R13NS040925-09), the National Institutes of Health Office of Rare Diseases Research, the Child Neurology Society, and the Children's Hemiplegia and Stroke Association. This research was carried out at the Children's Hospital of Alabama and supported by Grant HD040692 from the National Center for Medical Rehabilitation Research of NICHD. This work also was presented in part at the meeting of the Society for Neuroscience, October 14–15, 2006, Atlanta, GA. The authors thank Melanie Fridl Ross, MSJ, ELS, for editing assistance.

Financial Disclosure: None of the authors have financial relationships relevant to this article to disclose.

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 is considerable question 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 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 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 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 with the upper extremity of children ages 8 months to 8 years old 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 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 therapy 6 months after initial enrollment.

Since the initial study from this laboratory,²⁸ a number of other pediatric constraint-induced 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 pre-treatment testing shown in Table 2. Two children assigned to the control group dropped out before treatment began, one because of a seizure and one because of an indefinite hospitalization. Thus, at pre-treatment testing there were 10 participants each in the Immediate Constraint-Induced Therapy Group and the Usual and Customary Care Control Group; 9 of the latter were crossed over to constraint-induced 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 the following: stroke in the prenatal, perinatal, or very early antenatal period confirmed by magnetic resonance images obtained from medical records or personal physicians, upper extremity hemiparesis, age 2 to 6 years old, no serious or recurring medical complications, 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 the following: 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 (see below), uncontrolled seizures, botulinum toxin in the upper extremity or other spasticity medication within 3 months of pre-treatment testing, no fixed contractures in the affected upper extremity that would limit activity engagement (i.e., a 4 or greater on the Ashworth Scale at any joint), and previous constraint-induced 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.

Study Design

Children were assigned randomly in blocks of 4 to either a group receiving constraint-induced therapy immediately or a group that was tested, received usual and customary care for 6 months, and was then crossed over to constraint-induced 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 6 hours/day 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 in order to obtain 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 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 (e.g., 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 one dried, a second cast was used. Children adapted to the casts easily with complaints infrequently extending beyond the first day. The process of adaptation was little different than 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 (e.g., 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 (see below) 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 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 caregiver or therapist to keep reminding the child to use the more affected arm in activities of daily living; and
- (9) Monitoring of compliance by the caregivers with the instructed post-treatment 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, et al., 2006, unpublished data).

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 Patterns), and a laboratory motor function test that measures use of the affected extremity when it is requested (Pediatric Arm Function Test). Constraint-induced 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} (Uswatte G, Taub, E Griffin A, Vogtle L, Rowe A, Barman J. 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 21 upper-extremity activities over a specified period (e.g., last week, since the last time I saw you). Both scales have 6 steps. Only the How Well scale scores are reported here, since the How Well and How Often scales provide redundant information (Uswatte G, Taub, E Griffin A, Vogtle L, Rowe A, Barman J. In manuscript). In this dataset, for example, the pre- to post-treatment 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 pre-treatment 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: It is common during constraint-induced 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, one of whom must be the therapist. The therapist videotapes the behavior for future reference. For a behavior to be considered present at pre-treatment it need be observed by just one source, either a parent or a trained professional.

Motor ability, impairment measures, and parent compliance in the laboratory

Pediatric Arm Function Test: The Pediatric Arm Function Test is a reliable and valid (Uswatte G, Taub E, Vogtle L, Rowe A, Griffin A, Barman J. 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 score 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: Since it is impractical to use goniometers with young children, Passive range of motion and active range of motion were rated on a 4-point scale for 20 commonly measured movements immediately before and after treatment. The pre-treatment 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 therapy was evaluated by comparing pre- to post-treatment changes in the Immediate Constraint-Induced Therapy Group to corresponding changes in the Usual and Customary Care Control Group using mixed-model analysis of variance (ANOVA). Repeated-measures ANOVAs tested retention of gains over follow-up and the effect of crossing control children over to constraint-induced 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 pre-treatment characteristics and outcomes at post-treatment and 6-month follow-up in Immediate and Crossover Constraint-Induced therapy children combined. Effect sizes were indexed using Cohen's d (large $d = 0.4$) for between-group comparisons and Cohen's d' (large $d' = 0.57$) for within-group comparisons.⁶⁴

Significant gains after constraint-induced therapy in the 4 motor domains assessed were hypothesized based on prior studies.^{14,28}

Results

Immediate Effects of Constraint-Induced Therapy

Table 2 lists mean pre- and post-treatment scores and their standard deviation, effect size indices, and significance values. Children immediately after constraint-induced 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 Therapy Group had a very large increase on the Pediatric Motor Activity Log relative to the Control Group (2.2 vs. 0.1, $P < .0001$, $d = 3.8$). The Figure indicates that gains on the Pediatric Motor Activity Log were equally large after the Control Group was crossed over to constraint-induced therapy (mean pre- to post-constraint-induced therapy change = 2.1, $P < .0001$, $d' = 5.9$).

The Inventory of New Motor Activities and Program results indicate that a substantial number of new motor patterns performed with the more-impaired arm emerged during constraint-induced therapy, but few or none emerged during usual and customary care. For the Immediate Constraint-Induced 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 therapy, gains on the Inventory of New Motor Activities and Program were large (9.7, $P < .0001$, $d' = 3.1$).

On a laboratory motor function test, the Immediate Constraint-Induced Therapy Group, compared with the control group, showed large improvements in 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 Therapy children had a large pre- to post-treatment increase in the percent of tasks attempted with the more-impaired arm (11.9% to 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 therapy, the controls had a large increase (11.8% to 57.0%, $P = .004$, $d' = 1.3$). On the Pediatric Arm Function Test Functional Ability scale, which indicates quality of movement, Immediate Constraint-Induced 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 therapy, the controls showed a large increase in quality of movement (0.4 point increase, $P < .0001$, $d' = 2.7$).

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

Long-term Effects of Constraint-Induced Therapy

At 6-month follow-up, children in the Immediate Constraint-Induced 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 post-treatment to 6 months on the Inventory of New Motor Activities and Program or the Pediatric Arm Function Test or in active range of motion in the Immediate or Crossover Constraint-Induced Therapy Groups or at 1 year in the Immediate Group ($P > .09$ for all measures).

Table 3 lists 6-month outcomes. The Figure shows outcomes on the Pediatric Motor Activity Log in the Immediate Constraint-Induced Therapy Group up to 1 year after treatment and Crossover Constraint-Induced Therapy Group up to 6 months afterward. The Immediate Constraint-Induced Therapy Group had a reduction in Pediatric Motor Activity Log scores from post-treatment to 6-month follow-up (-0.7 ± 0.6 , $P = .005$, $d' = -1.2$), as did the Crossover Constraint-Induced 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 post-treatment in the Immediate Constraint-Induced Therapy Group was larger than at 6 months (-1.0 ± 0.8 , $P = .003$, $d' = -1.3$). One-year follow-up was not available for the Crossover Constraint-Induced Therapy Group. Nevertheless, both groups still had large Pediatric Motor Activity Log gains from pre-treatment at the end of follow-up ($P < .01$ for all measures, d' values > 1.2).

Relation of Pre-treatment Characteristics to Constraint-Induced Therapy Outcome

Immediately after constraint-induced 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 amount of spontaneous use of the more-impaired arm. This is consistent with our findings with adults. Correlations between pre-treatment severity of more affected arm motor impairment (see Appendix) and pre- to post-treatment gains on the Pediatric Motor Activity Log, Inventory of New Motor Activities and Program, 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 (i.e., high Inventory of New Motor Activities and Program scores) before treatment to have large post-treatment gains on the Pediatric Motor Activity Log and Pediatric Arm Function Test scales (range, $r = .52-.61$; range, $P = .028-.007$). Retention of post-treatment gains at 6-month follow-up, however, was not correlated with any of these measures.

An additional post-hoc 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 therapy. Parent cooperativeness during treatment, as rated by project staff, had a large correlation with post-treatment 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 therapy produced substantial improvement in the paretic arm of 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 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 a 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 post-treatment 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.

The Figure 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 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 validly^{60–62} (Uswatte G, Taub, E Griffin A, Vogtle L, Rowe A, Barman J. In manuscript) by use of the 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 therapy is particularly effective in overcoming learned nonuse and developmental disregard.

A number of studies have been reported in the literature in which constraint-induced 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 the Pediatric Motor Activity Log and derived from it with the collaboration of one of us (ET).

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 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 therapy termed “child-friendly” in 4- to 8-year-olds involving a day camp setting with restraint of the less-affected arm for just 6 hours/day. The interaction of subject with 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 post-treatment is significant and in one 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 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. Two still photographs from video demonstrating effect of constraint-induced therapy

Appendix Table A

Grading System for Severity of More-impaired Arm Motor Deficit in Children with Cerebral Palsy

Grade of Deficit	Joint				
	Shoulder	Elbow	Wrist	Fingers	Thumb
2 (Mild/Moderate)	WNL/mild limitation ^a 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 ^b 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 ^c 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		

Note: 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 one joint, he or she would be placed in the grade corresponding to the movement present at the worst joint.)

Abbreviations: WNL, within normal limits.

^aActive range of motion is >2/3 to just below normal range

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

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

Figure A.

Top panel. Pre-Constraint-Induced therapy—Self-feeding with a spoon. Limitations: weak grasp, no active wrist extension, needs assistance to pick up spoon and lift it to mouth, unable to turn wrist to get food in mouth.

Figure B.

Bottom panel. Post-Constraint-Induced therapy—Self-feeding with a spoon. Changes: successful on first attempt, improved wrist extension, independent in grasping spoon and bringing it to mouth, improved trunk stability.

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Figure 1.

Spontaneous use of the more impaired arm (Pediatric Motor Activity Log score) for the Immediate Constraint-Induced Therapy Group and the Control Group before and after crossover to constraint-induced therapy. Data for the Immediate Constraint-Induced 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 therapy. After crossover data are shown for treatment and 1 and 6 months afterward. Abbreviations: CI, constraint-induced; PMAL, Pediatric Motor Activity Log.

Table 1**Demographic and Cerebral Palsy-related Characteristics of Participants**

Characteristic	CI therapy (n = 10)	Controls (n = 10)
Age, mean yr $\pm$ 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, ^a n (%)		
Mild	3 (30)	5 (50)
Moderate	2 (20)	2 (20)
Moderately severe	3 (30)	2 (20) ^b
Severe	1 (10)	1 (10)
Very severe	1 (10)	0 (0)
History of Seizures, n (%)	4 (40)	1 (10)
PT/OT at enrollment, hr/wk ($\pm$ SD)	0.6 $\pm$ 0.5	1.0 $\pm$ 0.9

Note: There were no significant differences between the groups.

Abbreviations: CI, constraint-induced; PT, physical therapy; OT, occupational therapy; SD, standard deviation.

^a Actual range of motion criteria for classification of severity of impairment are given in the table in the Appendix.

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

Table 2
More-Impaired Arm Short-term Outcomes for Immediate CI Therapy, Control, and Crossover CI Therapy Children

Test	Immediate CI Therapy (n = 10)			Controls (n = 10)			Between-Gp Differences in Change		Crossover CI Therapy (n = 9) ^d			Within-Gp Pre to Post Change	
	Pre	Post	Change	Pre	Post	Change	<i>d</i> ^b	<i>P</i>	Pre	Post	Change	<i>d</i> ^c	<i>P</i> ^d
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	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	1.3	<.0001	29.2±5.2	38.9±3.7	9.7±3.2	3.1	<.0001
PAFT													
Unilat. tasks Af. arm use, % ^e	11.9±8.0	45.0±32.6	33.1±31.5	14.4±12.2	15.0±12.9	0.6±16.5	1.3	0.01	11.8±7.9	57.0±29.5	45.1±33.8	1.3	0.004
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	1.0	0.03	2.1±0.5	2.5±0.5	0.4±0.1	2.7	<.0001
Movements with a net increase in AROM, % ^f	.	.	71.1±11.4	.	.	7.6±9.1	1.7	<.0001	.	.	52.0±26.6	1.5	<.0001

Note: Values are mean points±SD.

Abbreviations: Af., affected; AROM, active range of motion; Gp, group; INMAP, Inventory of New Motor Activity and Patterns Test; PAFT, Pediatric Arm Function Test; PMAL, Pediatric Motor Activity Log; Unilat., unilateral; SD, standard deviation.

^aOne 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.

^bCohen's *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 post-treatment. For each outcome, it is the mean post-treatment value in the experimental group minus the corresponding value in the control group, all divided by the pooled standard deviation for these 2 scores.

^cCohen's *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.

^d*P* values are reported for repeated-measures ANOVA models with a specific contrast testing whether post-crossover constraint-induced therapy scores were different from trend in pre-crossover scores (i.e., baseline 1, baseline 2, and 6-month follow-up).

^eValues are for affected arm use for unilateral tasks only. For bilateral tasks, % of use of the affected arm also increased significantly after constraint-induced therapy when given immediately or after crossover, but the differences were smaller.

^fThis measure is the net number of 20 commonly tested upper-extremity movements with a positive change in active range of motion as a percent of the number of movements tested that were outside normal limits before treatment (i.e., those who had the potential to improve). Since this measure is a change score, pre- and post-treatment values are not reported. A between-group *t*-test was used to evaluate whether the difference in this metric between the Immediate Constraint-Induced Therapy and Control Groups at post-treatment is statistically significant, and Cohen's *d*, a between-group index of effect size, is used to indicate the magnitude of this difference.

Table 3

Pre- to Post-treatment and Pre- to Six-month Follow-up Changes in the Immediate CI Therapy, Control, and Crossover CI Therapy Conditions

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

Note: Values are mean points ± SD.

Abbreviations: Af., affected; AROM, active range of motion; Gp, group; INMAP, Inventory of New Motor Activity and Patterns Test; PAFT, Pediatric Arm Function Test; PMAL, Pediatric Motor Activity Log; Unilat., unilateral.

^a In the Crossover Constraint-Induced 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.

^b $P < .05$ for tests comparing either pre- to post-treatment or pre- to 6-month follow-up changes in the Immediate Constraint-Induced Therapy Group to corresponding changes in the control group.

^c $P < .05$ for tests comparing either pre-treatment scores to post-treatment or 6-month follow-up scores in the Crossover Constraint-Induced Therapy Group.

^d Values are for affected arm use for unilateral tasks only. For bilateral tasks, change in % of use of the affected arm from post-treatment to 6 months after treatment was also not significant when constraint-induced therapy was given immediately or after crossover.