Constraint-induced movement therapy: characterizing the intervention protocol

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Constraint-induced movement therapy (CI therapy) is a rehabilitation treatment approach that improves more-affected extremity use following a stroke, especially in the life situation. The originators of the approach describe CI therapy as consisting of a family of therapies including a number of treatment components and subcomponents. When thinking of CI therapy, rehabilitation researchers and clinicians frequently cite a restraining mitt on the less affected arm as the main active ingredient behind improvements in motor function. However, substantial data suggest that restraint makes actually a relatively small contribution to treatment outcome. This paper provides a detailed description of the multiple treatment elements included in the CI therapy protocol as used in our research laboratory. Our aim is to improve understanding of CI therapy and the research supporting its use.

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Stroke is the third leading cause of death in the United States after heart disease and cancer and a leading cause of serious, long-term disability. Profoundly impaired motor dysfunction is a major consequence of stroke.[1] Approximately half of the more than 700 000 people in the United States sustaining a stroke each year are left with significant permanent limitations in motor ability and compromised quality of life. From the early 1970s to the early 1990s, the estimated number of non-institutionalized survivors of stroke in the United States increased from 1.5 million to 2.4 million.[2] Medicare spent $3.6 billion in 1998 on stroke survivors discharged from short-stay hospitals. The American Heart Association estimates that the current direct and indirect costs of stroke in the United States are $43.3 billion per year. These percentages and cost estimates are probably similar throughout the industrialized world. The great prevalence of stroke and its high economic costs make the reduction of stroke-related disability a health care priority.

Unfortunately, the number of therapeutic interventions shown in controlled experiments to enhance motor function and promote independent use of an impaired upper extremity (UE) following stroke is quite limited.[3, 4] One reason for a lack of evidence could lie in a failure to adequately define the treatment

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approaches under study; leading to misunderstanding and failure to properly replicate and/or expand the research. Dijkers *et al.*, in a survey of "core" medical rehabilitation journals, noted that a common shortcoming of published intervention studies was the relative lack of conceptualization or detail in the description of treatment arms.[5] While the need to clearly specify and standardize interventions is not unique to rehabilitation research, the process is particularly challenging in this area. In many medical research endeavors, the treatment can be easily characterized, such as indicating a specific pharmaceutical dose. Complex interactions between clients and clinicians and the fact that most rehabilitation protocols contain multiple treatment components within a treatment system pose a substantial challenge to characterizing rehabilitation interventions.[6, 7] This type of intervention frequently involves complex descriptions of multiple components that require detailed attention to such issues as dose, intensity, frequency, timing, and method of interaction between the therapist and patient. Whyte *et al.* state that attention to intervention descriptions will "facilitate needed efficacy research, will allow replication of that research, and will ultimately foster dissemination of effective treatments into clinical practice".[6] Also, only through careful characterization can different components of an intervention be studied experimentally and examined for the active and inactive contributions to the treatment outcomes observed.

Constraint-induced movement therapy (CI therapy) involves a variety of components that are thought to promote increased use of the more-impaired UE both in the research laboratory/clinic and home settings.[8-13] The CI therapy protocol has its origins in basic animal research, conducted by one of us (E. T.) concerning the influence of the surgical abolition of sensation from a single forelimb by dorsal rhizotomy. This series of deafferentation studies led Taub to propose a behavioral mechanism that may interfere with recovery from a neurologic insult-learned nonuse.[14, 15] In more recent years, a linked but separate mechanism, use-dependent cortical reorganization, has also been proposed as partially responsible for producing positive outcomes from CI therapy.[16-21] Over the last 20 years, a substantial body of evidence has accumulated to support the efficacy of CI therapy for hemiparesis following chronic stroke, *i.e.*, >1-year postinjury.[11, 22] Evidence for efficacy includes results from: 1) an initial small, randomized controlled trial (RCT) of CI therapy in individuals with UE hemiparesis secondary to chronic stroke;[8] 2) a larger placebo controlled trial in individuals of the same chronicity and level of impairment;[23] and 3) a number of other studies.[9-13] There has also been a large, multisite randomized clinical trial in individuals with UE hemiparesis in the subacute phase of recovery, *i.e.*, 3-9 months poststroke.[24] Positive findings regarding CI therapy after chronic stroke are also published in several studies from other laboratories employing within-subjects control procedures and numerous case studies.[25-28] Moreover, the most recent poststroke clinical care guidelines describe CI therapy as an intervention that has evidence of benefit for survivors of stroke with mild-to-moderate UE hemiparesis.[4] To date over 150 papers making use of CI therapy have been published: all to our knowledge report positive results.

A detailed description of the CI therapy treatment elements will promote understanding of the approach and assist with future research efforts. To that end, the purpose of this article is to operationally define the CI therapy protocol as it is used in the research laboratory of the CI Therapy Research Group (CITRG) at the University of Alabama at Birmingham (UAB) and to compare the protocol to more conventional neurorehabilitation approaches.

The constraint-induced movement therapy protocol

CI therapy is a "therapeutic package" consisting of a number of different components. Some of these intervention elements have been employed in neurorehabilitation before; yet usually as individual procedures and at a reduced intensity compared to CI therapy. The main novel feature of CI therapy is the combination of these treatment components and their application in a prescribed, integrated and systematic manner to induce a patient to use a more-impaired UE for many hours a day for a period of 2 or 3 consecutive weeks (depending on the severity of the initial deficit). CI therapy has evolved and undergone modification over the 2 decades of its existence. However, most of the original treatment elements remain part of the standard procedure. The present CI therapy protocol, as applied in our research and clinical settings, consists of 3 main elements and multiple components and subcomponents under each (Table

I).[23, 29] These include: 1) repetitive, task-oriented training of the more-impaired UE for several hours a day for 10 or 15 consecutive weekdays (depending on the severity of the initial deficit); 2) applying a "transfer package" of adherence-enhancing behavioral methods designed to transfer gains made in the research laboratory or clinical setting to the patient's real-world environment; and 3) constraining the patient to use the more-impaired UE during waking hours over the course of treatment, sometimes by restraining the less-impaired UE. Each of the elements, component and subcomponent strategies are described in the following sections.

TABLE I.—*Components and subcomponents of the constraint-induced movement therapy protocol.*

Repetitive, task-oriented training
— Shaping
— Task practice
Adherence-enhancing behavioral strategies (*i.e.*, transfer package)
— Daily administration of the motor activity log
— Home diary
— Problem solving to overcome apparent barriers to use of the more affected upper extremity (UE) in the real-world situation
— Behavioral contract
— Caregiver contract
— Home skill assignment
— Home practice
— Daily schedule
Constraining use of the more-affected UE
— Mitt restraint
— Any method to continually remind the participant to use the more-affected UE

Repetitive, task-oriented training

On each of the weekdays during the intervention period, participants receive training, under the supervision of an interventionist, for several hours each day. The original protocol called for 6 h/day for this training. More recent studies indicate that a shorter daily training period (*i.e.*, 3 h/day) is as effective for higher functioning patients.[27, 28, 30-32] Two distinct training procedures are employed as patients practice functional task activities: shaping or task practice. Shaping is a training method based on the principles of behavioral training.[33-36] In this approach a motor or behavioral objective is approached in small steps by "successive approximations": for example, the task can be made more difficult in accordance with a participant's motor capabilities, or the requirement for speed of performance can be progressively increased. Each functional activity is practiced for a set of ten 30-s trials and explicit feedback is provided regarding the participant's performance during each trial.[36] Task practice is less structured (for example, the tasks are not set up to be carried out as individual trials of discrete movements): it involves functionally based activities performed continuously for a period of 15-20 min (*e.g.*, wrapping a present, writing). In successive periods of task practice, the spatial requirements of the activity, or other parameters (such as duration), can be changed to require more demanding control of limb segments for task completion. Global feedback about overall performance is provided at the end of the 15-20 min period. A large bank of tasks has been created for each type of training procedure. Tables II and III provide a more-detailed example of a shaping and a task practice activity, respectively. Interventionists are encouraged to provide 4 forms of interaction during the shaping and task practice activities. Table IV provides a description of this interaction and guidelines for applying them. Training tasks are selected for each participant considering: 1) specific joint movements that exhibit the most pronounced deficits; 2) the joint movements that trainers believe have the greatest potential for improvement; and 3) participant preference among tasks that have similar potential for producing specific improvement. Frequent rest intervals are provided throughout the training day and intensity of training (*i.e.*, the number of trials/hour (shaping) or the amount of time spent on each training procedure [task practice]) is recorded.

In an attempt to reduce the intensive therapist supervision required during training, automation has been successfully incorporated into CI therapy training.[30-32] A device termed AutoCITE (Automated Constraint-Induced Therapy Extender) was developed in collaboration between E. Taub and the UAB team and P. Lum and others at the VA Rehabilitation Research and Development Center in Palo Alto, CA, USA. The AutoCITE consists of a computer, eight-task devices arrayed in a cabinet on 4 tiered work surfaces, and an attached chair. The 8 activities are: reaching, tracing, peg board, supination/pronation, threading, arc-and-rings, finger-tapping, and object-flipping. The computer provides simple one-step instructions on a monitor that guides the participant through the entire treatment session. Completion of each instruction is verified by sensors, which are built into the

TABLE II.—*Example of a shaping task: placing blocks onto box.*

Activity description	A box and several blocks are used for this task. The subject moves small wooden blocks from the table to the top of a box. The placement and height of the box depend on the movements desired. For example, the box can be placed directly in front of the subject to challenge shoulder flexion and elbow extension or placed to the side to challenge shoulder abduction and elbow extension
Potential shaping level of difficulty progressions	Distance: the box can be moved farther away to challenge elbow extension Height: a higher box can be used to challenge shoulder flexion Size of object: larger or smaller blocks can be used to challenge wrist and hand control
Potential feedback parameters	Number of repetitions: number of blocks placed on the box in a given period of time Time: time required to place a set number of blocks on the box
Movements emphasized	Pincer grasp Wrist extension Elbow extension Shoulder flexion

TABLE III.—*Example of a task practice activity: folding/sorting clothes.*

Activity description	Subjects sit/stand at a table with a laundry basket in front of them. The basket is filled with washed cloths and towels of different colors The subjects remove the items, and sort them into piles of different colors After sorting, the subject proceeds to fold the items
Adjusting difficulty/complexity	Folding items can be graded from washcloths, to towels of different sizes, to clothes
Suggested feedback	Number of items sorted/folded in a set period of time (*e.g.*, 20 min) Time required sorting and folding entire basket of laundry Quality of folding (*e.g.*, cloths folded symmetrically) Improvement in hand function in performing these tasks (*e.g.*, thumb extension/opposition)

TABLE IV.—*Forms of interventionist/participant interaction used during shaping and task practice.*

Interaction type	Definition	Used in shaping	Used in task practice
Feedback	Providing specific knowledge of results about a participant's performance on a shaping trial or task practice session (*e.g.,* the number of repetitions in a set period of time or time required to perform a task or specific number of repetitions)	Provided immediately after each trial	Provided as global knowledge of results at the end of the entire task practice activity
Coaching	Providing specific suggestions to improve movements. Aspects of this procedure are described in the behavioral literature, as cuing and prompting	Provided liberally throughout all shaping trials	Provided throughout entire task practice session, though not as often as in shaping
Modeling	When a trainer physically demonstrates a task	Provided at the beginning of shaping activity. Repeated between trials as needed	Provided at the beginning of a task practice activity
Encouragement	Providing reward to participants to increase motivation and promote maximal effort (*i.e.*, "that's good, keep trying")	Provided liberally throughout all shaping trials	Provided throughout entire task practice session though not as often as in shaping

device. Task completion is recorded and displayed to participants before the next instruction is given. The participant is able to select tasks from a menu displayed on the monitor using two pushbuttons. Once a task has been chosen, the device automatically adjusts so that the appropriate work surface is at the correct height for task performance. The computer program guides the participant through a set of ten 30-s trials in which the objective is to repeat a task as many times as possible. After 10 trials, the task menu is displayed and the subject can select the next task. Several types of performance feedback and encouragement are provided on the computer monitor, simulating the type of verbal behavior engaged in by a therapist. The time remaining on each trial is shown on the computer monitor. The number of successful repetitions is displayed after each trial in the form of a bar added to a bar graph for each set of 10 trials. The activities are based upon tasks currently used in CI therapy. Studies using the AutoCITE during the CI therapy intervention indicate that gains achieved are substantial and comparable to those observed using CI therapy without automation.[30-32]

Adherence-enhancing behavioral methods to increase transfer to the life situation

One of the overriding goals of CI therapy is to transfer gains made in the research or clinical setting into the participant's real-world environment (*e.g.*, home and community settings). To achieve this goal, we employ a set of techniques that we term a "transfer package", which has the effect of making the patient accountable for adherence to the requirements of the therapy. The participant must be actively engaged in and adherent to the intervention without constant supervision from an interventionist, especially in the life situation where the interventionist is not present. Attention to adherence is directed towards using the more-impaired UE during functional tasks, and obtaining appropriate assistance from caregivers if present (*i.e.*, assistance to prevent the participant from struggling excessively but allowing them to try as many tasks by themselves as is feasible), and to wearing the mitt as much as possible (when it is safe to do so).

Potential solutions to these adherence challenges have been used to increase adherence to exercise in older adults; the population most commonly experiencing stroke and subsequently most likely to receive CI therapy.[37] Two psychological factors, self-efficacy and perceived barriers, have been identified as the strongest and most consistent predictors of adherence to physical activity in older adults. Self-efficacy is defined as an individual's confidence in his or her ability to engage in the activity on a regular basis.[38-41] It is related to both the adoption and maintenance of a target behavior. Studies have demonstrated that self-efficacy can be enhanced through training and feedback.[42-44] Perceived barriers may incorporate both objective and subjective components.[38-40] Objective obstacles can be reduced through environmental and task adaptation. Subjective barriers may be reduced by such interventions as confidence building, problem solving, and refuting the beliefs that hinder activity.

A number of individual intervention principles have been successfully applied to enhance adherence to exercise and physical function-oriented behaviors. Three are most relevant and are utilized in the adherence-enhancing behavioral components of CI therapy: monitoring, problem-solving, and behavioral contracting. Monitoring is one of the most commonly used strategies and involves asking participants to observe and document performance of target behaviors.[37] Participants can be asked to record a variety of aspects of these behaviors, including mode of activity, duration, frequency, perceived exertion, and psychological response to the activity. Participants should be asked to submit their monitoring records to others (*i.e.*, interventionists) to facilitate consistency and completeness of records as well as accountability to the self-monitoring strategy. Problem-solving interventions teach individuals to identify obstacles that hinder them, generate potential solutions, select a solution for implementation, evaluate the outcome, and choose another solution if needed.[39] Behavioral contracting involves asking participants to write out specific behaviors they normally carry out during the course of a day, and then entering into an agreement with the therapist as to which will be carried out by the subject and in what way they will be carried out. Verification of the execution of the contract occurs as part of the monitoring aspects of the procedure. Monitoring, problem-solving, and contracting interventions have been used successfully, alone or in combination, to enhance adherence to physical activity in a variety of participant groups with a variety of physical conditions. These are essential aspects of the CI therapy approach. The full range of adherence-enhancing behavioral subcomponents currently employed in the CI therapy protocol include daily administration of the motor activity log (MAL), a structured interview that elicits information on how well and how often the more affected UE was used in 30 important activities of daily life.[8, 45-47] a patient-kept home diary, problem solving, behavioral contracts with the patient and the caregiver independently, a daily schedule, home skill assignment and home practice. Each adherence-enhancing subcomponent is described below.

Monitoring: motor activity log and daily diary

The MAL is a structured interview during which respondents are asked to rate how much and how well they use their more affected arm for 30 important ADLs in the home over a specified period.[8, 45-47] The MAL is administered independently to the participant and an informant. The tasks include such activities as brushing teeth, buttoning a shirt or blouse, and eating with a fork or spoon. Information is gathered about more-affected UE use in the week and year prior to the participant's enrollment in the project, the day before and after the intervention, on each day of the intervention, weekly by phone for the 4 weeks after the end of treatment, and at several times during the two-year follow-up period. Several studies concerning the clinimetric properties of the MAL have shown the measure to be reliable and valid.[45-47] Moreover, the MAL does not produce a treatment effect when administered to persons not receiving a placebo treatment at the same treatment schedule as those receiving CI therapy.[23] Preliminary results from an ongoing experiment suggest that this self-monitoring instrument is a very important means of producing a transfer of improved performance from the laboratory/clinic to the life situation when used in conjunction with other aspects of the CI therapy treatment package, particularly concentrated training. The home diary is maintained on a daily basis. Participants list their activities outside the laboratory and report whether they have used their more affected extremity or not while performing different tasks, especially those listed on the behavioral contract (see below). The home diary and daily review of the MAL constitute the main monitoring aspects of the CI therapy protocol. They heighten participants' awareness of their use of the more-affected UE and emphasize adherence to the behavioral contract and the patients' accountability for their own improvement.

Problem solving

Discussion of the MAL and home diary also provides a structured opportunity for discussing why the weaker extremity was not used for specific activities and for problem-solving on how to use it more. For example, the participant may state that they are unable to pick up a sandwich with one hand and there for took the mitt off and used the less-affected UE to assist. The interventionist may then suggest that the participant cut the sandwich into quarters so that it is more easily manipulated with the weaker extremity. As another example, the participant might report that they are unable to open a door in their home because the doorknob is small and difficult to grip. The interventionist may provide the participant with a doorknob build-up and suggest that they use it so that the door can be opened with the more-affected UE.

Behavioral contract

The behavioral contract is a formal, written agreement between the interventionist and participant that the participant will use the more-affected extremity for specific activities in the life situation. In addition to increasing mitt use outside of the laboratory, the behavioral contract is helpful in assuring safety while wearing the mitt, engaging the participant in active problem-solving to increase adherence, and emphasizing participant accountability for adherence. The behavioral contract is completed at the end of the 1st day of treatment when the interventionist has assessed the participant's functional motor capacity and the participant has experienced using the mitt. Participants first list all activities of daily living (ADL) performed on a typical day. ADL are then categorized in the contract into those to be done with: a) the more-affected UE with the mitt on; b) both UEs with the mitt off; and c) less-affected UE only with the mitt off. The times agreed upon for "mitt off" activities is specified (*i.e.*, when it is to be removed and put back on), and have mainly to do with safety and the use of water. Activities may be added to increase UE use during otherwise inactive periods (*e.g.*, periodically turning pages of a magazine during time spent watching television). ADL may be modified to allow more-affected UE use (*e.g.*, using a spill-proof cup while drinking liquids, using a build-up orthotic device on the handle of a fork). The behavioral contract is signed by the interventionist, the participant and a witness; this formality emphasizes the importance of the agreement. The document is often modified during treatment as the participant gains new movement skills. The behavioral contract, monitoring and problem solving components of the transfer package mutually interact and support one another.

Caregiver contract

The caregiver contract is a formal, written agreement between the interventionist and the participant's caregiver that the caregiver will be present and available while the participant is wearing the mitt and will aid in the at-home program and more generally in helping to increase more-affected UE use. It is completed after the terms of the behavioral contract with the patient are shared with the caregiver. The caregiver contract a) improves caregivers' understanding of the treatment program, b) guides caregivers to assist appropriately, and c) increases the safety of the participant. The caregiver contract is signed by the interventionist, participant, and caregiver and thereby, again, formally emphasizes the importance of the agreement.

Home skill assignment

Wearing the mitt while away from the clinic/laboratory does not assure that participants will use the more-impaired UE to carry-out ADLS that had been accomplished exclusively with the less-impaired UE, or not at all, since the stroke. The home skill assignment process encourages the participant to try ADLs that they may not otherwise have tried with the more impaired UE. The interventionist first reviews a list of common ADL tasks carried out in the home. The tasks are categorized according to the rooms in which they are usually performed (*e.g.*, kitchen, bathroom, bedroom, office). Starting on the 2nd day of the intervention period, participants are asked to select 10 ADL tasks from the list that they agree to try after they leave the laboratory/clinic and before they return for the next day of treatment. Tasks not on the list may be selected if desired by the participant. These tasks are to be carried out while wearing the mitt when possible and safe. Interventionists guide the participant to select 5 tasks that the participant believes will be relatively easy to accomplish and 5 they believe will be more challenging. The 10 items selected are recorded on an assignment sheet and given to the participant when they leave the laboratory or clinic for the day. The goal is for approximately 30 min to be devoted to trying the specified ADLs at home each day. The home skill assignment sheet is reviewed during the first part of the next treatment day and 10 additional ADL tasks are selected for home skill assignment for that evening. This process is repeated throughout the intervention period with efforts made to encourage use of the more-impaired UE during as many different ADL tasks in as many different rooms of the participant's home as possible.

Home practice

During treatment, as an alternative to home skill assignment, participants are asked to spend 15 to 30 min at home on a daily basis performing specific upper-extremity tasks repetitively with their more-affected arm. This is referred to as home practice-during. The tasks typically employ materials that are commonly available (*e.g.*, stacking styrofoam cups). This strategy is particularly helpful for individuals who are typically relatively inactive while in their home setting (*e.g.*, spending long periods watching TV) and provides more structure to using the more-impaired UE than the home skill assignment. Care must be taken not to overload the participant with too many assignments while away from the laboratory/clinic as this could prove demotivating. For this reason interventionists usually select either home skill assignment or home practice-during to encourage more real world UE use; rarely are both used. Towards the end of treatment, an individualized post-treatment home practice program is drawn up consisting of tasks that are similar to those assigned in home practice-during; this is referred to as home practice-after. For each participant, 8-10 activities are selected based on the participant's remaining movement deficits. Participants are asked to demonstrate understanding and proficiency with all tasks before discharge. These tasks usually employ commonly available items to increase the likelihood that they will be implemented. Participants are encouraged to select 1 or 2 tasks/day and to perform these tasks for 30 min daily. On the next day, participants are asked to select 1 or 2 different tasks from the home practice-after assignment sheet. Participants are instructed to carry out these exercises indefinitely.

Daily schedule

Project staff record a detailed schedule of all clinical activities carried out on each day of the intervention. This includes time devoted to each activity listed. The schedule specifically notes the times when the restraint device is put on and taken off. The time and length of rest periods are also included. Specific shaping and task practice activities are listed including use of only the more-affected UE during lunch whenever it is feasible for the patient to come close to doing so. The daily schedule record includes not only the length of time devoted to eating lunch, but also what foods were eaten and how this was accomplished. Information recorded on the daily schedule is particularly helpful for demonstrating improvements in daily activities to the participant, which often has the effect of motivating them to try harder.

CONSTRAINING USE OF THE MORE-IMPAIRED UPPER EXTREMITY

The most commonly applied CI therapy treatment protocol has incorporated use of a restraint (either sling or protective safety mitt) on the less-impaired UE to prevent participants from succumbing to the strong urge to use that UE during most or all functional activities, even when the interventionist is present. Over the last decade, the protective safety mitt, which eliminates ability to use the fingers, has been preferred for restraint as it prevents functional use of the less-impaired UE for most purposes while still allowing protective extension of that UE in case of a loss of balance. When employed, participants are taught to put on and take off the mitt independently, and decisions are made with the interventionist as to when its use is feasible and safe. The goal for mitt use is 90% of waking hours. This so-called "forced use" is arguably the most visible element of the intervention to the rehabilitation community and is frequently and mistakenly described as synonymous with CI therapy. However, Taub *et al.*[9] has stated "there is… nothing talismanic about use of a sling, protective safety mitt or other constraining device on the less-affected UE" as long as the more-impaired UE is exclusively engaged in repeated practice. "Constraint", as used in the name of the therapy, was not intended to refer only to the application of a physical restraint, such as a mitt, but also to indicate a constraint of opportunity to use the less-impaired UE for functional activities.[9] As such, any strategy that encourages exclusive use of the more-impaired UE is viewed as a "constraining" component of the treatment package. For example, shaping was meant to be considered as constituting a very important constraint on behavior; either the participant succeeds at the task or he is not rewarded (*e.g.*, by praise or knowledge of improvement).

Preliminary findings by Sterr *et al.* indicate a significant treatment effect using CI therapy without the physical restraint component.[48] Likewise, our laboratory has obtained similar findings with a small group of participants (n=9) when a CI therapy protocol, without physical restraint was employed.[9, 13, 45] However, our study suggested that this group experienced a larger decrement at the two-year follow-up testing than groups where physical restraint was employed. If other treatment package elements, developed in our laboratory, are not used, our clinical experience suggests that routine reminders to not use the less-affected UE alone, without physical restraint, would not be as effective as using the mitt. Consequently, we use the mitt to minimize the need for the interventionist or caregiver to remind the participant to remember to limit use of the less-impaired UE during the intervention period.

Unique aspects of constraint-induced movement therapy as a rehabilitation approach

Three general approaches are commonly employed in the neurorehabilitation field to improve motor function after stroke:[49, 50] 1) compensation refers to modification of ADL so that they can be performed primarily with the less-affected side of the body. The more-affected extremities would at most be used as a prop or assist. This approach is believed to be particularly useful when spontaneous recovery of function has plateaued and further recovery seems doubtful; 2) in more recent years a more optimistic view has been adopted; as a result, emphasis on regaining movement on the more-affected side of the body has been advocated. With one such approach, true recovery, a specific function is considered "recovered" if it is performed in the same manner and with the same efficiency and effectiveness as before the stroke; 3) with a substitution approach, the more-affected extremities may be used in new way compared to before the neurologic insult to perform a functional task. The question regarding which approach to rehabilitation is most effective has been an ongoing debate in the neurorehabilitation field for many years.

A definition of conventional physical rehabilitation is difficult to formulate because the treatments employed are so diverse and are not connected by a single conceptual formulation. However, trends apparent in the content of popular physical rehabilitation textbooks, evaluative criteria for professional educational programs, and topics commonly addressed in continuing education courses suggest that conventional physical rehabilitation currently includes a predominance of either a true recovery or compensation approach to intervention. Further, due mainly to reimbursement policies, most intervention in the United States is delivered in short treatment periods, relative to CI therapy, and in a distributed manner. The CI therapy approach, as used in the UAB research laboratory and clinic, represents a substantial paradigm shift for conventional physical rehabilitation. The CI therapy approach is different from the more conventional compensation and functional recovery ap-proaches in a variety of important ways.

Importance of concentrated practice

While the CI therapy protocol used most often includes some sort of restraint on the less-affected UE, variations in this approach (*i.e.*, shaping only, intensive physical rehabilitation) do not.[45] There is thus, as already noted, nothing talismanic about use of a restraining device on the less-affected UE. The common factor in all of the techniques, producing an equivalently large treatment effect, appears to be repeatedly practicing use of the more-affected UE. Any technique that induces a patient to use a more-affected UE many hours a day for a period of consecutive weeks should be therapeutically efficacious. This factor is likely to produce the use-dependent cortical reorganization found to result from CI therapy and is presumed to be the basis for the long-term increase in the amount of use of the more-affected limb. Butefisch *et al.* and Hesse *et al.* have also shown that repetitive practice is an important factor in stroke rehabilitation interventions.[51-53] Conventional physical rehabilitation, regardless of setting (*i.e.*, inpatient or outpatient) or stage of rehabilitation (*i.e.*, acute, subacute, or chronic), does not provide a sufficient concentration of practice to achieve optimal results. The conventional schedule falls short not only in absolute amount time that using the more-affected UE is required, but also in the concentrated nature of the practice periods (*i.e.*, movements/h).

Shaping as a training technique

CI therapy studies have used predominately either task practice or shaping for training activities in the laboratory. Preliminary data suggests that use of either technique for higher functioning participants appears to be beneficial. However, our clinical experience is that a predominance of shaping in the training procedures is more effective for lower functioning participants than a predominance of task practice. While there are many similarities between shaping and the conventional training techniques used by therapists, important differences also exist. Shaping procedures use a highly standardized and systematic approach to increasing the difficulty level of motor tasks attempted. Also, feedback provided in shaping is immediate, specific, quantitative and emphasizes only positive aspects of the participants' performance. In this way, the therapist's input and continuous encouragement motivates the participant to put forth continued and maximal effort. Tasks are used that emphasize movements in need of improvement yet are at the upper end of the range that can be accomplished by the participant. Excessive effort is avoided as it may bring about a demotivating effect for the participant. Shaping is a behavioral technique and is directed toward increasing the amount and extent of use of the more affected UE during training. The main objective is to get the patient to use the more-affected UE repeatedly in a concentrated fashion to both overcome learned nonuse and induce use-dependent cortical reorganization. Skill acquisition regarding the specific shaping task practiced is not the primary purpose of shaping. Instead, skill attained during practice of a shaping task is a very beneficial byproduct that is hopefully transferred into motor performance in the real world environment. Specific skill acquisition with functional tasks is probably also encouraged during the independent trial and error occurring outside of the laboratory with use of the protective safety mitt during ADL in the participants' home environments.

Use of adherence-enhancing behavioral components

Another unique aspect of the CI therapy approach involves an emphasis on the use of behavioral techniques to facilitate transfer of more-affected UE use from the laboratory/clinic to the real-world environment. These adherence-enhancing behavioral techniques, discussed above, include use of two self-monitoring instruments (MAL and home diary), problem solving, home skill assignment, maintenance of a daily schedule, and behavioral contracts. While the use of similar behavioral techniques has been described in the physical rehabilitation literature, their use in combination and with the intensity with which they are used in the CI therapy protocol is different. The use of these behavioral techniques provides multiple opportunities for systematically increasing attention to more-affected UE use, promoting participants' accountability for adhering to the CI therapy protocol, and providing structured problem-solving between participants and research personnel. Intensive contact with the therapist establishes an important rapport between therapist and patient, which helps in getting the patient to take home practice and mitt-wearing requirements of the therapy very seriously.

Use of more-affected extremity

Use of restraint of the less affected hand is another unique aspect of CI therapy. As noted, the evidence indicates that it is the least important element of CI therapy. However, it is not without interest. For example, if the less-affected UE was the dominant UE before the stroke and the task was typically performed by the dominant UE (*e.g.*, writing), the CI therapy protocol still requires the participant to perform the task with the more-affected, non-dominant UE. This remains true for tasks that are bilateral in nature (*i.e.*, folding clothing). Instead of removing the mitt and performing the task with both UEs, the participants perform the task, in a modified fashion, with the more-affected UE exclusively or they enlist the assistance of a caregiver to serve as a "second UE." Many of the CI therapy participants' ADL are modified during the training period. In this way, the CI therapy protocol does not allow compensation and deviates from a functional recovery approach where all ADL would be attempted in the "typical" manner they were performed before the stroke. The purpose of the strict adherence to use of the protective safety mitt is not to encourage a permanent change in the way the participant performs ADL. Rather, use of the protective safety mitt requires the concentrated and repetitive use of the more-affected UE that leads both to overcoming the strongly learned habit of nonuse and to use-dependent cortical reorganization. Once the treatment period (*i.e.*, 2 or 3 weeks) has ended, participants return the protective safety mitt to the laboratory staff and perform ADL in the most effective manner possible with enhanced use of the more-affected UE. Interestingly, anecdotal observations suggest that after treatment many participants with more-affected, non-dominant UEs begin using the more-affected, non-dominant UE for tasks previously performed with the dominant, less-affected UE. Such observations warrant further investigation.

Main effect of constraint-induced movement therapy: increased use in the real-world situation

Since a true recovery approach promotes performance of specific functional tasks in a similar manner to that carried out before the stroke, quality of movement in this approach would seem to be an important, if not primary, indicator of successful rehabilitation. Results from the wolf motor function test [54] (a laboratory motor function test of best effort that is frequently used in CI therapy research), suggest that participants do significantly improve their quality and skill of movement as a result of CI therapy. A considerably larger change, however, has been demonstrated for increased amount of use of the more-affected UE in the life situation, as evidenced by the results from the MAL and other measures of real-world extremity use (*i.e.*, the actual amount of use test, accelerometry). Thus, participants may well be developing new movement strategies to accomplish functional tasks. If so, this would further distinguish CI therapy from more true recovery oriented therapies (*i.e.*, recovery of prestroke mode of movement).

Consistency of constraint-induced movement therapy efficacy with general clinical experience

In 1979, Andrews *et al.* published an article entitled "Stroke recovery: he can but does he?" [55] To quote their abstract, "...it was found that there was a difference in what the patients could do in the unit and what they did do at home. Each activity of daily living was less well performed in the home situation in 25-45% cases". Most clinicians recognize the veracity of this statement. Indeed, decrement in performance outside the clinic environment is frequently reported as a source of intense frustration. Clinicians often work with patients intensively for one or more sessions resulting in a substantial improvement in some aspect of movement. However, by the time of the next therapy session, there have been varying degrees of regression. In fact, some clinicians report that they sometimes see degradation in motor patterns as soon as the patient crosses the threshold into the corridor just outside the therapy room.

Very little explicit attention has been paid to this dimension of treatment. A reasonably intensive search of the literature failed to reveal a single reference to this phenomenon. Similarly, very little attention has been paid to the Andrews *et al.* paper,[55] which has been virtually "lost in the literature". However, for many stroke and other types of patients we have worked with, there is undeniably a gap between performance in the clinic on laboratory motor tests when specific activities are requested and the actual amount of limb use in the home. This gap may be viewed as an index of learned nonuse; CI therapy operates in this window. It establishes a bridge between the laboratory or clinic and the life setting so that the therapeutic gains made in the clinic transfer maximally and contribute to the functional independence of the patient outside of the clinical setting. Thus, many patients, though exhibiting a pronounced initial motor deficit prior to therapy, might have a considerable latent capacity for motor improvement that could be brought to expression by CI therapy.

Conclusions

Recent discoveries about how the central nervous system responds to injury and how to retrain or remediate behaviors have given rise to effective new therapies in other laboratories for the rehabilitation of function after neurological injury.[10] Until now, neurorehabilitation has been largely static; few, if any, older treatments have received evidence-based demonstrations of efficacy.[10] However, a current melding of basic behavioral science with neuroscience gives promise of entirely new approaches to improving the behavioral, perceptual, and possibly cognitive capabilities of individuals who have sustained neurological damage. One such approach, CI therapy, has been shown to be effective for increasing real world use of a more-affected UE following stroke. The approach consists of multiple components and subcomponents that interact together to produce the positive outcomes realized by participants receiving the treatment package.

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