Method for Enhancing Real-World Use of a More Affected Arm in Chronic Stroke
Transfer Package of Constraint-Induced Movement Therapy

Edward Taub, PhD; Gitendra Uswatte, PhD; Victor W. Mark, MD; David M. Morris, PT, PhD; Joydip Barman, PhD; Mary H. Bowman, OTR/L, C/NDT; Camille Bryson, PT; Adriana Delgado, BS; Staci Bishop-McKay, BS

Background and Purpose—Constraint-induced movement therapy is a set of treatments for rehabilitating motor function after central nervous system damage. We assessed the roles of its 2 main components.

Methods—A 2×2 factorial components analysis with random assignment was conducted. The 2 factors were type of training and presence/absence of a set of techniques to facilitate transfer of therapeutic gains from the laboratory to the life situation (Transfer Package; TP). Participants (N=40) were outpatients ≥1-year after stroke with hemiparesis. The different treatments, which in each case targeted the more affected arm, lasted 3.5 hours/d for 10 weekdays. Spontaneous use of the more affected arm in daily life and maximum motor capacity of that arm in the laboratory were assessed with the Motor Activity Log and the Wolf Motor Function Test, respectively.

Results—Use of the TP, regardless of the type of training received, resulted in Motor Activity Log gains that were 2.4 times as large as the gains in its absence (P<0.01). These clinical results parallel previously reported effects of the TP on neuroplastic change. Both the TP and training by shaping enhanced gains on the Wolf Motor Function Test (P<0.05). The Motor Activity Log gains were retained without loss 1 year after treatment. An additional substudy (N=10) showed that a single component of the TP, weekly telephone contact with participants for 1 month after treatment, doubled Motor Activity Log scores at 6-month follow-up.

Conclusions—The TP is a method for enhancing both spontaneous use of a more affected arm after chronic stroke and its maximum motor capacity. Shaping enhances the latter. (Stroke. 2013;44:1383-1388.)

Key Words: constraint-induced movement therapy ■ hemiplegia ■ shaping ■ stroke rehabilitation ■ task practice ■ transfer package

Constraint-induced movement therapy (CI therapy) has been found in multiple randomized controlled trials to be efficacious for rehabilitating upper-extremity function in chronic and subacute stroke in adults1 and cerebral palsy in children from 1 year through adolescence.2 Case series support the efficacy of CI therapy for rehabilitating upper-extremity function in traumatic brain injury1 and multiple sclerosis,4 and lower-extremity function in chronic stroke,5 traumatic brain injury,6 and multiple sclerosis.7 The magnitude of the treatment effect that has been reported, however, has been markedly variable.

The upper-extremity CI therapy protocol, as practiced in this laboratory, consists of 4 basic components8–10: (1) intensive training of the more affected arm for multiple days; (2) training by shaping (see Interventions section); (3) the transfer package (TP), a set of behavioral techniques to facilitate transfer of therapeutic gains from the treatment setting to daily life (see Interventions section and Methods in the online-only Data Supplement); and (4) prolonged motor restriction of the less affected arm.

In a representative randomized controlled trial of the full CI therapy protocol from this laboratory with 41 patients with chronic stroke, the value of the effect size index d for post-treatment gains in real-world spontaneous use of the more affected arm was 3.6.8 For comparison, 0.8 is considered a large value in the meta-analysis literature.11 All but 2 of the >400 CI therapy studies published by other laboratories report a positive treatment effect, but it is usually smaller than that obtained here. For example, a widely cited meta-analysis reports a mean d value of 0.8 for 21 CI therapy studies (total

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Stroke is available at http://stroke.ahajournals.org DOI: 10.1161/STROKEAHA.111.000559
N=508), =1/3 the d value reported here. However, most of these studies used attenuated or partial versions of our method. The usual missing component is the TP. In contrast, the results from this laboratory have been largely duplicated in studies from 4 laboratories that adhered to our method and whose therapists were trained here. Previous studies have found prolonged restraint of the less affected arm is not necessary to obtain a full treatment effect. This article reports on a study testing the contribution of 2 other components: training with shaping and the TP. In a previous article derived from this study using voxel-based morphometry, we reported that treatment with the full CI therapy protocol, including the TP, resulted in a profuse increase in gray matter in motor areas of the brain. Use of the same protocol, but with no TP, did not produce any detectable neuroplastic changes. The clinical findings from the subjects in that study are reported here; subjects were recruited from 2005–2007.

**Study 1: Methods**

**Participants, Randomization, and Informed Consent**

Forty-five community residents ≥1-year after stroke with upper-extremity hemiparesis were enrolled; 40 completed treatment (Figure 1). All had mild-to-moderate motor impairment of the more affected arm, which is categorized as a grade 2 deficit according to a classification schema used in CI therapy studies (Table I in the online-only Data Supplement). Specifically, participants were required to have extension of ≥10° at the metacarpophalangeal and one of the interphalangeal joints of each finger, ≥10° extension or abduction of the thumb, and ≥20° extension of the wrist from a fully flexed starting position. Exclusion criteria were as follows: (1) presence of medical conditions severe enough to interfere with participation in treatment; (2) profound bilateral hearing loss with use of hearing aids (90 dB or worse); (3) legally blind status; (4) ferrous metal in the body or any condition that would preclude an MRI; (5) uncontrolled seizures; (6) pharmacological treatment, for example, botulinum toxin or oral/intrathecal baclofen; and (7) previous CI therapy.

All participants provided signed informed consent before randomization. The study was performed at the University of Alabama at Birmingham, where the institutional review board for human research approved the research. Participants were informed that they would be enrolling in a project to test the importance of different components of CI therapy. Participants were randomized in equal numbers using a computer-generated random numbers table to receive 1 of 4 possible combinations of the 2 factors to be tested: presence versus absence of the TP (+TP versus −TP) and training with shaping versus repetitive task practice (shaping versus repetition; Figure 1).

**Interventions**

Components analysis was conducted with a 2×2 factorial design. The possible combinations of the 2 treatment factors were represented by 4 separate groups: shaping+TP, repetition+TP, shaping-No TP, repetition-No TP.

For all groups, training took place for 10 consecutive weekdays; 3 hours/d training +0.5 hours/d TP for the 2 +TP groups, and 3.5 hours/d training for the 2 −TP groups. The amount of in-laboratory treatment and participant-therapist interaction was thus equivalent between groups. In the +TP groups, participants wore a heavily padded safety mitt on their less affected arm to prevent use of that hand for a target of 90% of waking hours for the entire 14-day treatment period (10 training days plus 4 weekend days). In the −TP groups, participants wore the safety mitt for only in-laboratory treatment.

**Shaping**

Shaping is a training method in which a motor or behavioral objective is approached in small steps by successive approximations (ie, a task is gradually made more difficult with respect to a participant’s motor capabilities). Its principles were explicitly formulated by Skinner, and they have been applied to the rehabilitation of movement. A more detailed description of the shaping process is presented in Methods in the online-only Data Supplement.

**Repetitive Task Practice**

The same or similar tasks were used with the same schedule of administration as in shaping, and the participants were encouraged to keep trying, but no feedback was given, and tasks of increasing difficulty were not introduced.

**Transfer Package**

The TP consists of a set of techniques in common use in the behavioral analysis field for the treatment of a variety of conditions, but they have not been used systematically in rehabilitation. The techniques used here are as follows: behavioral contracts, daily home diary, daily administration of the Motor Activity Log (MAL) to track amount and quality of use of the more affected arm in 30 important Activities of Daily Living (ADL), problem solving to overcome perceived barriers to more affected arm use in ADL performance, written assignment of practice at home of both tasks performed in the laboratory, and use of the more affected arm in specified ADL, post-treatment home skill practice assignments, weekly telephone calls for the first month after laboratory treatment in which the MAL is given, and problem solving performance. The procedures are described in detail in Methods in the online-only Data Supplement.

**Measures**

The MAL is a scripted, structured interview that is reliable and valid. Evidence for validity of the MAL includes a strong correlation (r, range =0.71–0.91; P≤0.01) with accerelometry, an objective measure of amount of movement in the life situation. Participants are asked to rate the quality of movement and amount of use of their more affected arm in daily life on 30 upper-extremity activities over a specified period (eg, past week, yesterday). Only the quality of movement rating, named the Arm Use scale, is reported here because the 2 ratings are highly correlated (r=0.95; P=0.0001), and hence redundant. The minimum detectable change on the MAL Arm Use scale is 0.5 points (10% of full scale range). The test score is the mean of the item scores. The Wolf Motor Function Test (WMFT) is a valid and reliable measure of...
in-laboratory motor capacity (ie, maximum ability), when a participant is asked to complete a task with the more affected arm.\textsuperscript{27,28} Time to complete each of 15 upper-extremity actions or tasks is recorded. The test score is the mean of the item “Performance Time scores” after transforming them into a rate (repetitions per minute).\textsuperscript{29} The MRI results from the subjects in this study have been reported previously.\textsuperscript{19}

**Data Analysis**

Mixed model, repeated measures ANOVAs were used to test the independent and interdependent effects, if any, of the presence of the TP and type of training on pre- to post-treatment outcomes. Parallel models, which substituted test scores at 1-year follow-up for the post-treatment values, were used to evaluate the long-term effects of these components of CI therapy. Inspection of the group means and corresponding confidence intervals permitted description of the differences in outcomes between particular groups and testing occasions. The analysis was conducted on a per-protocol basis because the purpose of this components analysis was to identify the contribution of receiving particular components of CI therapy on treatment outcome. Two-tailed tests with an \( \alpha \) of 0.05 were used. To control the study-wide inflation of type I error, simple contrasts (eg, comparing individual groups to one another) were only conducted if the relevant omnibus test was significant.\textsuperscript{30} The \( f \) statistic\textsuperscript{11} was used to index the effect size of the differences in treatment gains between the groups; values \( \geq 0.4 \) are considered large. The \( d' \) statistic was used
to index the effect size of the changes within each group or combination of groups; values ≥0.57 are considered large.

**Trial Profile and Initial Participant Characteristics**

Of 289 candidates screened by telephone, 56 were enrolled. Of this number, 45 were randomized to 1 of the 4 groups in Study 1, and 11 were randomized to the single group in Study 2 (see Study 2: Methods and Results). In Study 1, 89% completed treatment and 80% completed MALs at 1-year follow-up. There was no difference in drop-out between groups at either post-treatment (P=0.793) or 1-year follow-up (P=0.741). Figure 1 shows the trial profile and numbers randomized to and completing treatment in each group, along with reasons for drop-out.

**Study 1: Results**

Participants were, on average, 63 years of age (range =29–88) and 3.9 years after stroke (range =1.0–11.0). Thirty-eight were right dominant before stroke; 16 had paresis on the right side. There were no significant differences at pretreatment between the Study 1 groups on any of the characteristics listed in Table II in the online-only Data Supplement (P, range=0.16–0.36), including expectation of benefit from treatment (P=0.20). Nor were there pretreatment differences on the MAL (P=0.92; Table III in the online-only Data Supplement) or WMFT (P=0.74; Table IV in the online-only Data Supplement).

**Changes From Pre- to Post-treatment**

Table III in the online-only Data Supplement and Figure 2A show changes at post-treatment on the MAL. Use of the TP, regardless of type of training received, resulted in gains in spontaneous use of the more affected arm in the life situation that were significantly larger than those observed in its absence (mean difference in MAL gains =1.2 points; <0.01). Type P that were significantly larger than those observed in its absence spontaneously use of the more affected arm in the life situation. Six months after treatment substantially increased the spontaneous use of the more affected arm in the life situation. Six months after treatment, the MAL score in this group had decreased to the level of the Repetition−TP group at that occasion, suggesting that other elements of the TP are needed to sustain MAL gains over the longer-time interval at the higher level.

The magnitude of the enhancement in treatment outcome that were greater than the minimum detectable change on this test (Shaping−TP, mean=0.7; Repetition−TP, mean=0.8), the +TP groups had changes that were more than twice as large (Shaping+TP, mean=1.8; Repetition+TP, mean=2.1).

Table IV in the online-only Data Supplement and Figure 2C show post-treatment changes on the WMFT, which, as noted, measures maximum motor capacity in the laboratory. Use of the TP and training with shaping each made independent contributions to post-treatment WMFT Performance Rate gains (+TP versus −TP; mean difference =6.4 repetitions/min, P<0.05; Shaping versus Repetition, mean difference =5.4, P<0.05). Inspection of the mean changes within each group reveals that although the −TP groups had MAL gains that were greater than the minimum detectable change on this test (Shaping−TP, mean=0.7; Repetition−TP, mean=0.8), the +TP groups had changes that were more than twice as large (Shaping+TP, mean=1.8; Repetition+TP, mean=2.1).

**Overall Discussion**

The current consensus in physical rehabilitation, including the perspective of patients, researchers, clinicians, and health care payers, is that functional activity in the life situation is the most important outcome to pursue. The 2 TP groups scored a mean of 1.2 on the MAL Arm Use scale at the beginning of treatment and ended treatment 2 weeks later scoring 3.1. A rating of 3, according to the verbal anchor presented to participants, represents an ability to perform a daily life activity independently. A post-treatment test score of 3.1 indicates that after treatment, participants were performing approximately half the 30 ADLs tracked...
by the MAL without the aid of the less affected arm or an external source. Converting the mean scores to the percentile scale presented to participants, the spontaneous use of the more affected arm compared to before stroke improved from 12% before treatment to 53% after treatment, an increase of 4.4 times due to treatment. This is consistent with previous research from this laboratory.8,34

Improvement on the MAL at post-treatment was 2.4 times greater in the groups that received the TP than in the groups that did not, even though all groups received more affected arm training of the same duration and intensity. Moreover, this advantage persisted for the entire year of follow-up; there was no decrement in MAL gains in any of the Study 1 groups. The power of TP is further indicated by the fact that the introduction of a single one of its components in Study 2, weekly phone contacts for the first month after treatment, resulted in bridging the performance gap between groups with and without the TP at post-treatment by half, 6 months

Figure 2. Treatment outcome for real-world spontaneous use of more affected arm (Motor Activity Log [MAL]) and the maximum motor capacity of that extremity (Wolf Motor Function Test [WMFT] performance rate). MAL outcomes at post-treatment and 1-year follow-up are graphed in A and B, respectively. WMFT post-treatment outcomes are graphed in C. In all 3 panels, change from pretreatment is plotted. TP indicates transfer package.

Figure 3. Real-world constraint-induced movement (CI) therapy outcome for groups from study 1 with the transfer package (TP, Shaping+TP, Repetition+TP), no TP (Shaping−TP, Repetition−TP), and no TP during treatment but with phone contact in follow-up only (Study 2 participants). Study 2 participants, who did not receive the TP during treatment, had virtually the same pre- to post-treatment Motor Activity Log (MAL) gains as the −TP groups in Study 1, which were less than half of the MAL gains made by +TP groups in Study 1. After treatment, Study 2 participants had 4 weekly phone calls for the first month after treatment in which the MAL and problem solving were performed. Six months after treatment, approximately half the difference in spontaneous use of the more affected arm between the −TP and +TP groups had been bridged. Data is ipsitized (ie, scores at pretreatment are set to zero).
afterward. In future research, it would be of value to perform components analysis to determine the role of each of the individual elements of the TP.

The question arises as to whether the TP increases treatment effect by increasing the amount of practice of more affected arm use. Alternatively, it is possible that the TP promotes integration of therapeutic gains achieved in the laboratory into real-world activities so that more affected arm use becomes habitual. These 2 possibilities are not mutually exclusive. Addressing this question in future research would be of mechanistic and theoretical interest; however, from the point of view of practical therapeutics, the resolution of this important issue does not really matter. The TP seems to be a means of increasing real-world treatment outcome that does not involve increasing costly therapist time; this would be of considerable value whatever the mechanism by which the TP achieved its effect.

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**Disclosures**

None.

**References**

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SUPPLEMENTAL MATERIAL

Supplemental Methods

Shaping

For rehabilitation, shaping involves a) providing immediate and very frequent feedback concerning improvements in the quality of movement, b) selecting tasks that are tailored to address the motor deficits of individual participants, c) modeling, prompting, and cuing of task performance, and d) systematically increasing the difficulty level of the task performed in small steps when improvement is present for a period of time. A battery of over 120 tasks with a shaping plan for each has been developed by the CI Therapy Research Group. The principles for use as guidelines for shaping to induce recovery of motor function are presented in 1 (Appendix 1); 3 sample shaping tasks with shaping plans are also presented there. Training with adult participants is carried out in sets of 10 discrete 30 sec trials with 1 min rests between trials and longer rests between sets of trials as needed to reduce fatigue. Approximately twenty-five trials are given per hour; higher functioning participants sometimes need to be slowed down to equate amount of training between patients with different levels of motor ability. Task performance is timed by stopwatch and a written record of performance times is kept; it is referred to frequently and the time is reported to the participant at the end of each trial. This is typically highly motivating, encouraging the participants to keep trying to improve on their “personal best” in the manner of a video game. In this laboratory shaping has two distinct levels. The first level is directed toward improving the speed and quality of movement from trial to trial within a task with frequent feedback and encouragement being given. The second level involves introducing a new task that is similar to but more difficult than the one being used when motor performance improves to the point where the therapist feels that it can be accomplished by the participant.
(e.g., picking up and moving as many standard checker game counters as possible in 30 sec, followed after skill acquisition by use of slick round glass marbles). When the emphasis is on the between-level task modification process, the procedure is sometimes referred to as “adaptive task practice.” The procedure employed here involves use of both levels of shaping but focuses more attention on improving within-level task performance.

Component Procedures of the Transfer Package

Behavioral Contract. At the outset of treatment, the therapist negotiates a contract with the participant and separately with the caregiver, if one is available, in which they agree that the participant will use his or her more impaired arm as much as possible outside the laboratory and wear the restraint device whenever it is safe for up to 90% of waking hours. Specific activities during which the participant can practice using the more impaired arm are discussed and written down. At the end of this process, the negotiated document is signed by the patient (or caregiver), the therapist, and a witness to emphasize the character of the document as a contract.

Daily home diary. During treatment, the participants catalog how much they have used the more-affected arm for the activities specified in the behavioral contract and worn the restraint device. The diary is kept for the part of the day spent outside the laboratory and is reviewed in detail each morning with the therapist.

Daily administration of the Motor Activity Log (MAL). The MAL collects information about use of the more-affected arm in 30 important and commonly performed ADL. The daily repetition of “how well” participants complete the activities in this detailed report is probed and verified in a number of ways and serves to keep participants’ attention on use of the more-affected arm outside the laboratory.
**Problem Solving.** Daily during treatment and in four weekly phone contacts following treatment, the therapist helps participants to think through any barriers to using their more impaired arm and ways to overcome it. For example, if a participant is concerned about spilling liquid from a glass, the therapist may suggest only filling the glass half way. If a participant is embarrassed by clumsiness in use of the more-affected arm in feeding themselves in a restaurant (many of the laboratory’s patients are from out of town), the therapist may suggest eating in the hotel room.

**Home skill assignments during treatment.** Participants are assigned on a written check-off sheet 10 specific ADL tasks in which the more-affected arm should be used, with 5 easy tasks for that participant and 5 more difficult (e.g., carrying the mail, sorting the mail, opening the curtains, making the bed, feeding a pet). Alternately, the participants might be assigned 6 tasks daily similar to ones carried out in the laboratory (3 easy and 3 more difficult) on a written check-off sheet to be performed repetitively with their more-affected arm. The tasks typically use materials that are commonly available (e.g., transferring dried beans on a spoon from one bowl to another) and are chosen for practice to improve the participant’s most significant movement deficits.

When answers to the MAL or check-off lists indicate a lack of performance, the therapist can then inquire into the reasons for this and problem solve with the participant/caregiver on how to reverse this trend.

**Home skill assignments after treatment.** Toward the end of treatment, a written individualized post-treatment home skill practice program is developed and given to the patient. There are 7 separate lists, one for each day of the week, that are to be repeated weekly. Each list contains 3 repetitive tasks to be carried out for 15-30 minutes and 7 ADL in which the participant is asked to use the more-affected hand selected from a list of approximately 400 developed by the laboratory.
Post-treatment telephone contacts. Participants are contacted weekly for the month after treatment by telephone. During each contact the How Well and How Often Scales of the MAL are administered and problem solving is carried out.

The strategies used in the CI therapy transfer package are in common use in behavioral interventions for treating such problems as disruptive classroom behaviors, drug addiction, and medication adherence; but they have not been employed in a systematic way in physical neurorehabilitation. 4

Self-monitoring is one of the most commonly used strategies and involves asking participants to observe and document their target behaviors. 5-12 For example, Rhode et al. showed the importance of self-monitoring in transferring behavior treatment gains from a resource room to regular classroom situation. 13 When self-monitoring interventions were utilized in the resource room only, children's behavior improved only in this setting. However, when these same interventions were implemented in the classroom, behavior gains generalized to the classroom setting and were persistent even after termination of the intervention. 13 Just the act of monitoring a target behavior is thought to be effective because it helps patients attend to appropriate stimuli and is self-reinforcing. In CI therapy, for example, recording instances when the more-impaired arm is used in a daily diary may help participants to immediately notice small, gradual improvements in use of their arm that participants would not notice otherwise until later in treatment when improvements are more pronounced. The MAL carried out in interaction with the therapist also has an important self-monitoring function.

Contracting, i.e. negotiating specific behaviors that participants agree to do, has also been shown to be efficacious in promoting behavior change. Contracting indicates the behaviors that a participant agrees to carry out and those that are not acceptable. Positive findings for contracting
have been observed in treatment of cocaine-dependent outpatients$^{14}$ and adherence to behavior modification training for parents of children with behavior problems.$^{15}$ The CI therapy transfer package uses contracting with both participants and caregivers to increase compliance with home-based portions of the therapy. For the participant, this includes attempting to use the more-impaired arm at home, wearing the restraint device on the less-impaired arm, and doing home skill practice exercises; for the caregiver the behavioral contract might involve agreement to assist in the performance of certain activities in a gradually diminishing fashion, but often more importantly to provide less help for the participant in carrying out other activities with the more-impaired arm. The behavioral contract is frequently renegotiated part-way through treatment as the participant’s motor ability improves.

Telephone contacts are also a means of increasing treatment compliance. They have been successful at promoting behavior change in a variety of areas, such as increasing fruit and vegetable consumption,$^{16}$ reducing HbA1c levels in diabetics,$^{17}$ increasing physical activity,$^{18}$ and complying with mammography recommendations.$^{19}$ Mixed results have been obtained in studies employing telephone interventions to promote compliance with pharmacological management of hypertension$^{20,21}$ and to reduce coronary disease.$^{22}$ However, the interventions used varied widely between studies, possibly accounting for the array of findings. In CI therapy, the 4 weekly follow-up phone calls in the first month after treatment, which include administration of the MAL, is thought to be effective in increasing adherence to CI therapy at home by extending therapist-reinforcement of increased more-impaired arm use into the post-treatment period. The follow-up phone calls also provide an opportunity for therapists to continue to model problem-solving for participants.
Problem-solving interventions can also be effective for overcoming barriers to behavior change. Problem-solving interventions teach individuals to identify obstacles that hinder them, generate potential solutions, select a solution to implement, evaluate the outcome, and choose another solution if needed. Problem-solving interventions have been associated with positive health behavior changes such as managing diabetes, compliance with rheumatoid arthritis treatment, and relief of anxiety/depression symptoms. In CI therapy, therapists help participants to find solutions to apparent obstacles to use of their more-impaired arm that participants raise when reviewing the daily diary or completing the MAL. It is thought that by modeling appropriate problem-solving behavior during CI therapy and in the follow-up MAL telephone contacts, the therapists stimulate participants to effectively solve new problems that arise in using their more-impaired arm after in-person contact with therapists has ended.

Function of the Transfer Package

In most rehabilitation regimens, the participant is required to carry out exercises guided by a therapist primarily during treatment sessions. The TP makes the patient a more active participant in their own improvement, not only during the treatment sessions but also at home. The TP provides a systematic means of specifying explicitly what the participant is expected to do when outside the treatment setting, monitoring what in fact is done, and providing a structure within which to solve apparent barriers to carrying out treatment goals. Thus, the TP permits participants to be immersed in a therapeutic environment for a meaningful portion of their day. Therapy is not confined to the limited period that the current reimbursement system permits. It has been recognized by many therapists from the outset of the rehabilitation field that optimal therapy would be carried out “24/7”. Application of the TP may represent an initial step in this direction. Finally, it should be noted that the TP can be used in conjunction with many other
physical rehabilitation regimens and can be carried out in a relatively brief period of time.
Therefore, it might be possible to employ it with other rehabilitation treatments to increase their outcome.
ONLINE SUPPLEMENT

Supplemental Tables
<table>
<thead>
<tr>
<th>Severity of Impairment</th>
<th>Shoulder</th>
<th>Elbow</th>
<th>Wrist</th>
<th>Fingers</th>
<th>Thumb</th>
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<tbody>
<tr>
<td>Grade 2</td>
<td>Flexion ≥45° and Abduction ≥45°</td>
<td>Extension ≥20° from a 90° flexed starting position</td>
<td>Extension ≥20° from a fully flexed starting position</td>
<td>Extension of all MCP and IP (either PIP or DIP) joints ≥10°</td>
<td>Extension or abduction of thumb ≥10°</td>
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<tr>
<td>Grade 3</td>
<td>Flexion ≥45° and Abduction ≥45°</td>
<td>Extension ≥20° from a 90° flexed starting position</td>
<td>Extension ≥10° from a fully flexed starting position</td>
<td>Extension ≥10° MCP and IP (either PIP or DIP) joints of at least 2 fingers†</td>
<td>Extension or abduction of thumb ≥10°</td>
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<td>Grade 4</td>
<td>Flexion ≥45° and Abduction ≥45°</td>
<td>Extension ≥20° from a 90° flexed starting position</td>
<td>Extension ≥10° from a fully flexed starting position</td>
<td>Extension of at least 2 fingers &gt;0° and &lt;10°‡</td>
<td>Extension or abduction of thumb ≥10°</td>
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<td>Grade 5A§</td>
<td>At least one of the following: Flexion ≥30° abduction ≥30° scaption ≥30°</td>
<td>Initiation of extension</td>
<td>Must be able to either initiate extension of the wrist or initiate extension of one digit</td>
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<td>Grade 5B§</td>
<td>At least one of the following: Flexion ≥30° abduction ≥30° scaption ≥30°</td>
<td>Extension ≥20° from a 90° flexed starting position</td>
<td></td>
<td>No active movement required for the wrist, fingers, or thumb</td>
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</table>

*In this system, people are placed in the highest grade at which they can meet or exceed each minimum movement criterion for each joint 3 times in 1 minute. Anybody who cannot meet the minimum movement criterion for Grade 5A or 5B is placed in Grade 6. Importantly, placement in any of the Grades also requires a substantial deficit in use of the more-affected arm as documented by a score of less than 2.5 on MAL (see Measures) and a minimum degree of passive ROM. For Grades 2–4 the minimum passive ROM criteria are: shoulder flexion and abduction of at least 90° and shoulder external rotation of at least 45°, elbow extension to within 30° of the normal limit, forearm supination to at least 45°, forearm pronation to at least 45° from neutral, wrist extension to at least neutral, and MCP joint extension to within 35° of the normal limit. For Grades 5A and 5B, the passive ROM criteria are the same, except for the following relaxations of the requirements: a) forearm supination to neutral instead of to 45° and b) wrist extension to within 45° of normal limit.
neutral instead of to neutral. †Informally assessed by being able to pick up and drop a tennis ball. ‡Informally assessed by being able to pick up and drop a washcloth. §Grade 5B is distinguished from 5A by the absence of any active extension at the wrist, fingers, or thumb on the more-affected hand. However, greater active extension of the elbow is required for Grade 5B than 5A. Without a greater degree of movement at the elbow to compensate for the lack of any movement at the hand, the movement capacity specified by Grade 5B would be too low to permit training with even rudimentary functional tasks. Note that people who meet the Grade 5A hand and Grade 5B elbow criteria would be placed in Grade 5A. People who meet the Grade 5B hand criterion but fail to meet the Grade-5B elbow criterion, even though they exceed the Grade 5A elbow criterion, would fall into Grade 6. || Initiation is defined here as minimal movement, i.e., below the level that can be measured reliably by goniometry.

CIMT=Constraint-Induced Movement therapy. MCP= metacarpophalangeal; IP=interphalangeal. PIP=proximal interphalangeal. DIP=distal interphalangeal. ROM=range of motion. MAL=Motor Activity Log.
Table S2. Participants’ pre-treatment characteristics

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Study 1</th>
<th>Study 2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Shaping+TP (n=10)</td>
<td>Shaping-TP (n=10)</td>
</tr>
<tr>
<td>Time since stroke, years</td>
<td>2.3 (1.4-3.3)</td>
<td>4.3 (0.8-7.8)</td>
</tr>
<tr>
<td>CI</td>
<td>(0.9-4.8)</td>
<td>(1.0-11.1)</td>
</tr>
<tr>
<td>Demographic</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age, years</td>
<td>61.0 (29.3-77.5)</td>
<td>63.5 (46.4-84.5)</td>
</tr>
<tr>
<td>Range</td>
<td>(29.3-72.2)</td>
<td>(52.6-74.4)</td>
</tr>
<tr>
<td>CI</td>
<td>(49.9-72.2)</td>
<td>(52.6-74.4)</td>
</tr>
<tr>
<td>Female</td>
<td>6</td>
<td>5</td>
</tr>
<tr>
<td>European-American</td>
<td>6</td>
<td>4</td>
</tr>
<tr>
<td>African-American</td>
<td>3</td>
<td>6</td>
</tr>
<tr>
<td>Other</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Side of paresis</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Right</td>
<td>3</td>
<td>6</td>
</tr>
<tr>
<td>Pre-stroke dominant side</td>
<td>10 (10)</td>
<td>10 (10)</td>
</tr>
<tr>
<td>Expectations (range, 1-7)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Benefit from therapy</td>
<td>6.6 (6.1-7.0)</td>
<td>5.7 (4.2-6.8)</td>
</tr>
<tr>
<td>(range, 1-7)</td>
<td>(range, 1-7)</td>
<td>(range, 1-7)</td>
</tr>
</tbody>
</table>

Note: Values are mean (95%CI). There were no differences between the groups in Study 1 (P, range=0.16-0.36). There were also no differences between the Study 1 and Study 2 participants (P, range=0.32-0.83). Shaping=training with shaping, Repetition=repetitive task practice, +TP=presence of Transfer Package, -TP=absence of Transfer Package.
## Table S3. MAL Arm Use scores (range=0-5 points) for the Treatment Groups with Training using Shaping vs. Repetition and Transfer Package (+TP) vs. no TP (-TP)

<table>
<thead>
<tr>
<th>Group</th>
<th>Pre</th>
<th>Post</th>
<th>1-year</th>
<th>$n$</th>
<th>Post-Pre Change Effect Size</th>
<th>1-year-Pre $n^a$</th>
<th>Change Effect Size</th>
</tr>
</thead>
<tbody>
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<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Treatment Changes Within Each Group</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shaping+TP</td>
<td>1.0</td>
<td>2.9</td>
<td>3.2</td>
<td>10</td>
<td>(1.1-1.8) $^b$</td>
<td>7</td>
<td>(0.8-0.6) $^b$</td>
</tr>
<tr>
<td></td>
<td>(0.7-1.4)</td>
<td>(2.2-3.5)</td>
<td>(2.4-4.1)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Repetition+TP</td>
<td>1.3</td>
<td>3.3</td>
<td>3.3</td>
<td>10</td>
<td>(1.6-3.2) $^b$</td>
<td>9</td>
<td>(1.2-1.9) $^b$</td>
</tr>
<tr>
<td></td>
<td>(0.7-1.8)</td>
<td>(2.7-4.0)</td>
<td>(2.1-4.4)</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Shaping–TP</td>
<td>1.1</td>
<td>1.8</td>
<td>2.0</td>
<td>10</td>
<td>(0.2-1.1) $^b$</td>
<td>8</td>
<td>(0.2-1.1) $^b$</td>
</tr>
<tr>
<td></td>
<td>(0.4-1.7)</td>
<td>(1.0-2.6)</td>
<td>(0.9-3.2)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Repetition–TP</td>
<td>1.2</td>
<td>2.1</td>
<td>2.4</td>
<td>10</td>
<td>(0.4-1.5) $^b$</td>
<td>8</td>
<td>(0.5-1.6) $^b$</td>
</tr>
<tr>
<td></td>
<td>(0.6-1.8)</td>
<td>(1.3-2.8)</td>
<td>(1.7-3.1)</td>
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</tr>
<tr>
<td><strong>All Combined</strong></td>
<td>1.2</td>
<td>2.5</td>
<td>2.7</td>
<td>40</td>
<td>(1.1-1.5) $^b$</td>
<td>32</td>
<td>(1.1-1.4) $^b$</td>
</tr>
<tr>
<td></td>
<td>(0.9-1.4)</td>
<td>(2.1-2.9)</td>
<td>(2.3-3.2)</td>
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<td></td>
<td></td>
</tr>
<tr>
<td><strong>Differences in Gains Between the Groups With and Without Transfer Package</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shaping+TP &amp; Repetition+TP</td>
<td>1.2</td>
<td>3.1</td>
<td>3.2</td>
<td>20</td>
<td>(1.6-2.3) $^b$</td>
<td>16</td>
<td>(1.4-1.8) $^b$</td>
</tr>
<tr>
<td></td>
<td>(0.8-1.5)</td>
<td>(2.7-3.5)</td>
<td>(2.5-3.9)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shaping–TP &amp; Repetition–TP</td>
<td>1.2</td>
<td>1.9</td>
<td>2.2</td>
<td>20</td>
<td>(0.5-1.3) $^b$</td>
<td>16</td>
<td>(0.6-1.3) $^b$</td>
</tr>
<tr>
<td></td>
<td>(0.8-1.6)</td>
<td>(1.4-2.4)</td>
<td>(1.6-2.8)</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>+TP vs. –TP</strong></td>
<td>0.0</td>
<td>1.2</td>
<td>1.0</td>
<td>40</td>
<td>(1.1-1.3) $^c$</td>
<td>32</td>
<td>(1.0-1.1) $^c$</td>
</tr>
<tr>
<td></td>
<td>(0.0-0.0)</td>
<td>(1.1-1.3)</td>
<td>(0.9-1.0)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Differences in Gains Between the Groups With and Without Training Using Shaping</strong></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shaping+TP &amp; Shaping–TP</td>
<td>1.1</td>
<td>2.3</td>
<td>2.6</td>
<td>20</td>
<td>(1.3-1.3) $^b$</td>
<td>15</td>
<td>(0.8-1.2) $^b$</td>
</tr>
<tr>
<td></td>
<td>(0.7-1.4)</td>
<td>(1.8-1.9)</td>
<td>(0.8-1.3)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Repetition+TP &amp; Repetition–TP</td>
<td>1.2 (0.9-1.6)</td>
<td>2.8)</td>
<td>3.3)</td>
<td>1.7)</td>
<td>2.0)</td>
<td>2.7</td>
<td>2.9</td>
</tr>
<tr>
<td>-------------------------------</td>
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</tbody>
</table>

| Shaping vs. Repetition        | 0.2 (0.1-0.3)  | 0.4 (0.3-0.5) | 0.3 | 0.3 | 0.2 | 40 | 0.3 | 0.1c | 32 | (0.1-0.2) | 0.1c |

Note. *P<0.05, **P<0.01, ***P<0.001. The interaction effect (Type of Training x Presence of Transfer Package) was not significant at post-treatment (P=.795) or at 1-year follow-up (P=.365). Hence, no simple contrasts were conducted. In other words, statistical testing was only conducted for the 3 rows shaded in grey. The first of which presents data that are the basis for the omnibus test of the effect of treatment on MAL scores, regardless of presence or absence of the TP and type of training. The data in the second and third rows shaded in grey are the basis for the omnibus tests of the main effects of presence of the TP and type of training, respectively. Since statistical testing was not conducted for the data in the other rows, the absence of a symbol marking a P value <0.05 does not indicate that the change observed was not statistically significant. aReasons for missing data are given in the trial profile in Figure 1. As noted in Study 1: Methods, there was no difference in incidence of missing data across groups. Furthermore, the post-treatment MAL scores of the 20% of participants without data at 1-year were not significantly different from the post-treatment scores of those with 1-year data, which suggests that dissatisfaction with small treatment gains was not the reason that the participants had missing 1-year data (P=0.508). bCohen’s d’ is a repeated measures index of effect size (large d’=.57); it is the mean pre- to post-treatment change divided by the SD of the change.27 cCohen’s f is a measure of effect size (large f = 0.4); it indexes the magnitude of the difference in pre- to post-treatment change between the two groups being compared. For example, for the test of the effect of type of training, it is the variance in MAL scores accounted for by type of training (shaping vs. repetition) x testing occasion (pre, post) interaction divided by the error variance for this factor.27 MAL=Motor Activity Log.

No sex-based or racial/ethnic-based differences were present.
Table S4. WMFT Performance Rate Scores (repetitions/minute) for the Treatment Groups with Training using Shaping vs. Repetition and Transfer Package (+TP) vs. no TP (-TP)

<table>
<thead>
<tr>
<th>Group</th>
<th>Pre</th>
<th>Post</th>
<th>Change</th>
<th>Effect Size</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre- to Post-treatment Changes Within Each Group</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shaping+TP</td>
<td>29.3</td>
<td>40.9</td>
<td>11.6</td>
<td>1.0a</td>
</tr>
<tr>
<td></td>
<td>(21.2-37.5)</td>
<td>(29.4-52.4)</td>
<td>(3.3-19.9)</td>
<td></td>
</tr>
<tr>
<td>Repetition+TP</td>
<td>36.2</td>
<td>41.9</td>
<td>5.7</td>
<td>0.9a</td>
</tr>
<tr>
<td></td>
<td>(26.0-46.4)</td>
<td>(31.0-52.8)</td>
<td>(1.2-10.1)</td>
<td></td>
</tr>
<tr>
<td>Shaping–TP</td>
<td>32.4</td>
<td>37.1</td>
<td>4.7</td>
<td>1.1a</td>
</tr>
<tr>
<td></td>
<td>(19.3-45.5)</td>
<td>(23.2-50.9)</td>
<td>(1.6-7.8)</td>
<td></td>
</tr>
<tr>
<td>Repetition–TP</td>
<td>34.5</td>
<td>34.2</td>
<td>-0.3</td>
<td>-0.1a</td>
</tr>
<tr>
<td></td>
<td>(25.1-43.9)</td>
<td>(23.8-44.5)</td>
<td>(-5.3-4.6)</td>
<td></td>
</tr>
<tr>
<td>All Combined</td>
<td>33.1</td>
<td>38.5</td>
<td>5.4</td>
<td>0.6a</td>
</tr>
<tr>
<td></td>
<td>(28.6-37.7)</td>
<td>(33.4-43.7)</td>
<td>(2.7-8.2)</td>
<td></td>
</tr>
</tbody>
</table>

Differences in Gains Between the Groups With and Without Transfer Package

<table>
<thead>
<tr>
<th>Group</th>
<th>Pre</th>
<th>Post</th>
<th>Change</th>
<th>Effect Size</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shaping+TP &amp; Repetition+TP</td>
<td>32.8</td>
<td>41.4</td>
<td>8.6</td>
<td>0.9a</td>
</tr>
<tr>
<td></td>
<td>(26.7-38.9)</td>
<td>(34.3-48.6)</td>
<td>(4.2-13.1)</td>
<td></td>
</tr>
<tr>
<td>Shaping–TP &amp; Repetition–TP</td>
<td>33.5</td>
<td>35.6</td>
<td>2.2</td>
<td>0.4a</td>
</tr>
<tr>
<td></td>
<td>(26.2-40.7)</td>
<td>(27.8-43.5)</td>
<td>(-0.7-5.1)</td>
<td></td>
</tr>
<tr>
<td>+TP vs. –TP</td>
<td>0.7</td>
<td>5.8</td>
<td>6.4**</td>
<td>0.4b</td>
</tr>
<tr>
<td></td>
<td>(0.0-1.4)</td>
<td>(5.0-6.6)</td>
<td>(6.0-6.8)</td>
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</table>

Differences in Gains Between the Groups With and Without Training Using Shaping

<table>
<thead>
<tr>
<th>Group</th>
<th>Pre</th>
<th>Post</th>
<th>Change</th>
<th>Effect Size</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shaping + TP &amp; Shaping – TP</td>
<td>30.9</td>
<td>39.0</td>
<td>8.1</td>
<td>0.9a</td>
</tr>
<tr>
<td></td>
<td>(23.9-37.9)</td>
<td>(30.9-47.2)</td>
<td>(3.8-12.5)</td>
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</tr>
<tr>
<td>Repetition + TP &amp; Repetition – TP</td>
<td>35.4</td>
<td>38.0</td>
<td>2.7</td>
<td>0.4a</td>
</tr>
<tr>
<td></td>
<td>(29.1-41.6)</td>
<td>(31.0-45.1)</td>
<td>(-0.7-6.0)</td>
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</tr>
<tr>
<td>Shaping vs. Repetition</td>
<td>4.5</td>
<td>1.0</td>
<td>5.4*</td>
<td>0.3b</td>
</tr>
<tr>
<td></td>
<td>(3.8-5.2)</td>
<td>(0.2-1.8)</td>
<td>(5.0-5.8)</td>
<td></td>
</tr>
</tbody>
</table>

Note. *P<0.05, **P<0.01, ***P<0.001. The interaction effect (Type of Training x Presence of Transfer Package) was not significant (P=.858). Hence, no simple contrasts were conducted. In other words, statistical testing was only conducted for the 3 rows shaded in grey. The first of which presents data that are the basis for the omnibus test of the effect of treatment on WMFT scores, regardless of presence or absence of the TP and type of training. The data in the second and third rows shaded in grey are the basis for the omnibus tests of the main effects of presence of the TP and type of training, respectively. Since statistical testing was not conducted for the data
in the other rows, the absence of a symbol marking a $P$ value $<0.05$ does not indicate that the change observed was not statistically significant. There were no missing data at post-treatment. However, 1-year follow-up data are not reported for the WMFT because about half of the participants lived out of town and did not return to the laboratory on this testing occasion. Only 20% of the data were missing for the MAL because this instrument can be administered over the telephone if necessary. $^a$Cohen’s $d'$ is a repeated measures index of effect size (large $d'=.57$); it is the mean pre- to post-treatment change divided by the $SD$ of the change.$^{27}$ $^b$Cohen’s $f$ is a measure of effect size (large $f=0.4$); it indexes the magnitude of the difference in pre- to post-treatment change between the two groups being compared. For example, for the test of the effect of type of training, it is the variance in WFMT scores accounted for by type of training (shaping vs. repetition) x testing occasion (pre, post) interaction divided by the error variance for this factor.$^{27}$ WMFT=Wolf Motor Function Test.
Table S5. MAL Arm Use and WMFT Performance Rate Scores for Study 2 Participants

<table>
<thead>
<tr>
<th></th>
<th>Pre</th>
<th>Post</th>
<th>1-month</th>
<th>6-month</th>
<th>1-year</th>
<th>Change from Pre to Post</th>
<th>Change from Pre to 1-month</th>
<th>Change from Pre to 6-month</th>
<th>Change from Pre to 1-year</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>MAL Arm Use scale (range=0-5 points)</strong></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Mean</td>
<td>1.3</td>
<td>2.0</td>
<td>2.5</td>
<td>3.0</td>
<td>2.1</td>
<td>0.7*</td>
<td>1.3**</td>
<td>1.5**</td>
<td>0.8**</td>
</tr>
<tr>
<td>95% Confidence Interval</td>
<td>(0.6-1.9)</td>
<td>(0.9-3.1)</td>
<td>(1.5-3.6)</td>
<td>(1.7-4.2)</td>
<td>(1.0-3.1)</td>
<td>(0.2-1.3)</td>
<td>(0.7-1.8)</td>
<td>(0.8-2.1)</td>
<td>(0.3-1.3)</td>
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<td>Effect Size(^a)</td>
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<td></td>
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<tr>
<td><strong>WMFT Performance Rate (repetitions/minute)</strong></td>
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</tr>
<tr>
<td>Mean</td>
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<td>35.9</td>
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<td>na</td>
<td>8.5**</td>
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<td>95% Confidence Interval</td>
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<td>(17.8-53.9)</td>
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<td>(3.1-13.9)</td>
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<td>Effect Size(^a)</td>
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Note. *\(P<0.05\), **\(P<0.01\). Study 2 participants received repetitive task practice without a TP during treatment and the MAL component of the TP weekly for 4-weeks afterwards. Their pre-treatment MAL and WMFT scores were not significantly different from the corresponding scores for all Study 1 participants \(P_{s}\geq 0.67\). WMFT data were not collected at the 1- and 6-month follow-ups. As in the case of Study 1, one-year follow-up data are not reported for the WMFT because about half of the participants did not return to the laboratory on this testing occasion. Only 20% of the data were missing for the MAL because this instrument can be administered over the telephone if necessary. \(^{a}\)Cohen’s \(d'\) is a repeated measures index of effect size (large \(d'=.57\)); it is the mean pre- to post-treatment change divided by the \(SD\) of the change. \(^{27}\) MAL=Motor Activity Log, WMFT=Wolf Motor Function Test, na=not available. TP=transfer package.
Supplemental References


