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The Effects of Constraint-Induced Therapy on Precision Grip: A Preliminary Study

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Abstract

Objective—This preliminary study examines the effects of a 2-week constraint-induced therapy (CIT) intervention on the force-producing capabilities of the hemiparetic hand during the performance of a functional dexterous manipulation task.

Methods—A 6-degree-of-freedom force/torque transducer that was embedded into the handle of a key allowed for the quantification of grasping forces and torques produced during the performance of a functional key-turning task. Clinical and kinetic data were collected from 10 subacute patients (3–9 months poststroke) who were participating in an ongoing national clinical study (EXCITE trial) examining the effects of CIT on upper extremity motor performance. Investigators were blinded to treatment designation. Five patients receiving treatment immediately completed 2 weeks of intensive CIT, whereas a group randomized to treatment 1 year later did not receive any therapy during a similar 2-week span.

Results—Results indicated that 4 of the 5 patients in the CIT group, compared to the delayed group, showed significant clinical improvements in hand function, increased maximum precision grip force, improved force and torque regulation, and reduced variability in rate of force production during task performance.

Conclusions—Improved force control may be a mechanism contributing to the observed improvements in dexterous function in those patients undergoing CIT.

Keywords

Constraint-induced therapy; Precision Grip; Dexterous function

Stroke continues to be the 3rd leading cause of disability in the United States, with approximately 750,000 new or recurrent cases each year. Despite improvements in gait, a large percentage of stroke patients are limited in the performance of many daily activities, such as dressing and eating.¹ One third to two thirds of stroke survivors may no longer be able to use their more affected upper extremity (UE).^{2,3} One approach that is gaining interest, aimed at enhancing UE motor performance among patients with stroke, is constraint-induced movement therapy (CIT).^{4,5}

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Forced use⁶ and CIT are neurorehabilitation techniques that have been shown to improve motor function of the hemiparetic limb of stroke patients.⁷ A typical CIT program consists of a period of intensive motor training in the form of repetitive and adaptive task practice of the more affected limb while activity of the less affected limb is constrained by a mitt or sling.^{5,8} During these intensive sessions, a trainer supervises the practice of functional patient-selected tasks. The demands of the task are increased as gains are made.

The underlying mechanism(s) responsible for improved motor function of patients undergoing CIT is not well understood. A possible reason for this lack of understanding may lie in the methods used in assessing UE functions, especially those governing the hand. Most studies rely on clinical tests (Wolf Motor Function Test [WMFT], Fugl-Meyer Assessment Test [FMA], Frenchay Arm Test, Nine Hole Peg Test, self-report Motor Activity Log [MAL]) or maximum grip strength (using a power grip) to assess UE and hand function pre-post CIT. In general, these tests provide clinical information regarding functional status of the impaired limb or how fast a patient can complete a series of tasks, or they assess the patient's perception of how well he or she can use his or her UE. More objective outcome measures are necessary if the mechanisms underlying stroke motor deficits and CIT are to be understood.

This preliminary study aimed to determine the effects of a 2-week CIT intervention on the force-producing capabilities of the hemiparetic hand during the performance of a functional dexterous task. A secondary aim was to determine the feasibility of using this functional dexterous manipulation task along with biomechanical measures to quantify hand function of stroke patients in a clinical setting. Although others⁹⁻¹¹ have studied the effects of stroke on reaching and grasping, to our knowledge, this is the 1st investigation in which grasping forces and torques produced during a functional task were quantified in an attempt to understand how CIT affects grasping force control.

METHODS

Participants

Data were collected from 10 right-handed sub-acute patients (3–9 months since stroke) who were participating in an ongoing national clinical trial examining the effects of CIT on UE motor performance and quality of life.⁸ Study design, including detailed inclusion and exclusion criteria, has been reported previously.⁸ Briefly, all patients had only 1 stroke, at least 20 degrees active wrist extension, 10 degrees active finger extension, minimum passive range of motion of 90 degrees for shoulder flexion and abduction, score of at least 24 on the Mini Mental State Exam, and they were not receiving any other therapy at the time of the study (for more details, see previous publication⁸). Ten patients were randomly assigned to 1 of 2 groups; immediate or delayed CIT. Patients assigned to the immediate group began CIT approximately 3 days after their preintervention evaluations, whereas the delayed group was scheduled to receive CIT approximately 1 year later. Group assignment was unknown to the investigators. Only after posttest data were completely analyzed was the principal investigator of the EXCITE trial (SLW) informed of group assignment. Patient demographics are provided in Table 1. Written informed consent was obtained before participation from each patient in accordance with the Emory University institutional review board.

CIT Intervention

The immediate group underwent 2 weeks of CIT in which the less affected hand was placed in a mitt. Patients wore this mitt for approximately 90% of their waking hours during the intervention. These patients attended CIT training sessions 5 days per week for up to 6 h per

day for 2 consecutive weeks. Shaping, or adaptive task practice and repetitive task practice techniques were used during the training sessions. Typical activities included stacking checkers, flipping cards, picking up marbles, insertion of bolts in holes, stacking canned goods, and other activities similar to those performed on a daily basis. All training was one-on-one with a rehabilitation specialist.

Data Collection

Prior to group assignment, all patients performed the maximum precision grip and key-turning experiments. Patients in the immediate group repeated the experiment after completing the CIT program (posttest data were gathered within 1 week after their final CIT session). Patients in the delayed group were tested 2 weeks after their initial group assignment. During this interval, the delayed group members did not participate in any formal rehabilitation programs. Clinical motor function data were collected for both groups after group assignment and approximately 2 weeks later. The WMFT¹² and FMA (Arm and Hand section; maximum score 66, where higher scores indicate greater function) were used as clinical markers of UE motor function. The WMFT is designed to assess the motor ability of patients with moderate to severe UE motor deficits in the laboratory and clinic and is composed of functional activities, such as lifting a pencil and folding a towel and turning a key in a lock. Fifteen of the 17 items are timed, whereas the other 2 items assess strength; the final time score is the median time required for all timed tasks performance. An evaluator blinded to group assignment performed pre- and post-WMFT and FMA assessments.

Maximum Grip Force Testing

For maximum force trials, participants used their best precision grip to exert their maximum force against a Nano-17 Model force transducer that was embedded in the handle of a key. Data from three 10-sec trials were collected with the more affected hand, 2-min rest between trials. Patients were instructed to exert maximum effort during each trial while the experimenter verbally encouraged the patient to continue squeezing with greater effort. The highest force achieved on these trials was considered their maximum.

Key-Turning Task

A modified version of the key-turning task in the WMFT was used to assess grasping forces. Figure 1A provides an illustration of the experimental setup. A standard dead-bolt lock was affixed to a wooden support. To simulate the resistance experienced when opening a lock, a spring was placed within the internal locking mechanism; thus, as participants turned the key to the left or right of center, resistance to movement increased. A housing was machined to hold the transducer in the handle of the key. Grasping forces and torques were collected at 200 Hz. The forces and torques about each axis are shown in Figure 1B (grip force was defined as F_z , whereas load force is the resultant force of F_x and F_y). Data were collected with a customized LabView program. Force and torque data were digitally filtered with a 4th-order no-phase-lag filter with a cutoff = 10.43 Hz and processed off-line using MatLab.

Prior to each trial, the experimenter ensured that the key was securely inserted in the lock at the 12 o'clock or 0° position. An auditory "Go" from the computer signaled the patient to reach and grasp the handle of the key, using precision grip if possible. Upon reaching the key, participants turned it clockwise 90° (3 o'clock position), back to 0°, counterclockwise 90° (9 o'clock position), and returned back at the 0° position. Reference lines were drawn on the key support to guide key-turning amplitude. The elastic resistance at the two 90° degree locations was approximately 0.75 N/m. No specific instructions were given to the patient regarding the speed of key-turning. Five trials were attempted with the more affected hand (1-min rest between trials). Force and torque profiles for a healthy adult (46-year-old male)

are provided in Figure 1C. These data were used to develop an algorithm to approximate key position while performing key-turning task. The key-turning task was *not* included as one of the activities performed during the 2 weeks of CIT training. The kinetic data were collected at the Emory study site, whereas all kinetic analyses were performed at Georgia Tech by blinded technicians not involved in data collection.

Data Analysis

A 2×2 (group $\times$ time) repeated measures ANOVA was used to identify any interaction or main effects. In cases where statistical significance ($P < 0.05$) was observed, paired t tests were used to follow up any interaction or main effects. Because this study was preliminary in nature, greater emphasis was placed on individual patient data analysis and trends within each group.

RESULTS

Clinical Assessment

Individual patient and group WMFT change from pre- to postdata for the timed components along with the time to perform the key-turning task and FMA data, for the more affected hand during pre- and posttest sessions, are provided in Table 1. A nearly significant group-by-time interaction was present for the overall change in WMFT median time ($F_{1,8} = 4.15$, $P = 0.07$). Results indicated that 4 of the 5 patients in the immediate group exhibited a decrease in the median time to perform the tasks within the WMFT (where lower numbers indicate less time to complete tasks). The total time to perform these tasks was reduced, on average 27.9%, with the range of reduction from 15% to 60%. Two patients in the delayed group did reduce their times, whereas 3 patients actually increased their performance times. On average, the delayed group showed a 5.6% increase in overall WMFT time. There were no significant differences between the delayed and immediate group on the FMA test from pre- to postassessment conditions. As shown in Table 1, no clear trend or pattern of results was present regarding the change in FMA score between the 2 groups.

In general, all patients, during the pretest used what could be characterized as a “modified pinch grip” compared to a traditional precision grip. With the modified pinch grip, the key was typically contacted with the pad of the thumb and lateral border of the index finger compared to a traditional precision grip in which the pads of the thumb and index finger are in contact with the object (key). After CI training, 3 patients in the immediate group transitioned to using a more traditional precision grip whereas the remaining patients continued to use a variation of the “modified pinch grip.” Four of the 5 patients in the immediate group showed a reduction in the time to perform the key-turning task. One patient (pt. 8) in the immediate group was not able to complete the task during pre- or posttest sessions. Overall, the immediate group reduced movement time by 47% after CIT. Four of the 5 patients in the delayed group did not exhibit any change in their movement time from pre- to posttest sessions. Two patients in the delayed group were not able to perform the key-turning task in either session. One patient in the delayed group required more time to perform the task in the posttest compared to the pretest. On average, the delayed group required 15% more time to perform the key-turning task in the posttest than pre-test session. Statistically there were no significant interactions or main effects, as the variability within and between groups was substantial.

Strength Changes

Patients in the immediate group increased maximum grip force, whereas patients in the delayed group showed little change in maximum force. A significant group-by-time interaction was present for maximum precision grip force ($F_{1,8} = 6.80$; $P < 0.05$). Patients in

the immediate group showed a significant increase in their maximum force-producing capabilities as force increased from 11.3 N to 19.9 N after the CIT intervention ($t_{1,4} = -2.76$; $P = 0.05$). Pretest (14.5 N) and posttest (15.0 N) maximum forces were not different for the delayed group. Both groups' maximum strength was less than that typically produced by younger college-aged adults (52.68 N) and healthy older adults (48.76 N) in our earlier studies.

Grasping Forces and Torques during Key-Turning

Representative force and torque profiles for patients in the immediate and delayed group while performing the key-turning task with the more-affected hand during the pretest session are provided in Figure 2. Inspection of the grasping data gathered in the pretest session indicates that patients in both groups produced irregular and nonsystematic grasping forces. Despite the inconsistent force profiles produced during these trials, the patients successfully performed the task as instructed (e.g., turn the key to the right, back to the center, and then to the left). Torque profiles in the X and Y dimensions during these turning actions were equally irregular and nonsystematic across patients in both groups.

Grasping force and torque data from the posttest session, patients in the immediate and delayed groups, are provided in Figure 3. Grasping forces produced by those in the delayed group were similar from pre- to posttest conditions. The delayed group continued to produce irregular and uncoupled grip and load forces. Inspection of the grasping profiles for the patients undergoing CIT indicates that the generation of grip force improved in the posttest compared to pretest performance. The most striking feature of grasping forces produced by patients after CIT was their relatively smooth and monotonic increase in grip force production, compared to pretest conditions. Further inspection of their grasping profiles indicates that 2 dominant control patterns emerged in the controlling of their grasping forces. One patient (pt. 10) tended to produce a grip force that was sufficiently large throughout the key-turning action; this strategy allowed the patient to maintain contact with the key to overcome changes in load force and torques while turning. Three of the patients (pt. 9, Figure 3; pts. 6 and 7, Figure 4) from the immediate group appeared to modulate grip force during key-turning as indicated by the distinctive peaks in the grip and load forces. As these patients initiated key-turning from the start position (#1-hatched arrow) to position 2 (filled arrow), a monotonic increase in grip force was observed. When turning the key back from position 2 to position 3 (open arrow), these patients reduced grip force as they turned the key back to the initial position and then increased grip force while turning the key to position 3. Finally, patients reduced grip force as they returned the key to the initial position. The reduction in grip force when turning the key back toward the starting position may reflect patients' taking advantage of the reduction in resistance as the spring was being unloaded. One patient in the immediate group (pt. 8) did not demonstrate any qualitative changes in the consistency or smoothness of grip force production; furthermore, this patient was not able to successfully perform the task in the allotted 2 min in either the pre- or posttesting sessions.

The rate ($\Delta f/\Delta t$) of grip force profiles for 5 successful key-turning trials for pre- and posttest sessions for 1 patient from the delayed group and 1 from the immediate group are shown in Figure 5. Plots A and C of Figure 5 represent the rate of grip force production for a patient in the delayed group during pre- and posttesting sessions, respectively. This patient produced force-rate profiles that were multi-peaked, irregular, and nonsystematic. Plots B and D of Figure 5 represent grip force-rate profiles for a patient in the immediate group. During the pretest (plot B), the patient produced force-rate profiles that were similar to patients in the delayed group (e.g., multiple peaks and nonsystematic). However, after CIT (plot D), this patient consistently produced smooth, bimodal force-rate profiles.

The time difference between the onset of grip force and the onset of a torque in the X or Y axes (e.g., preload time) was calculated to examine simultaneity of force/torque control. Preload time data are provided in Table 1. Although there were no significant differences between groups in terms of pre- to posttest measurements, there was a trend for the patients in the immediate group to decrease their preloading times compared to the delayed group. Three of the patients in the immediate group did exhibit substantial reductions in preload time. Patients in the delayed group did not demonstrate marked improvement in their preloading times.

DISCUSSION

The aim of this preliminary study was to assess changes in the control of grasping forces in patients with subacute stroke who participated in an intensive 2-week CIT program. Results indicated that CIT, in general, led to an increase in maximum precision grip force and improved consistency and modulation of grasping forces. Results from the clinical motor assessment measure (WMFT) indicated the CIT led to an overall improvement in UE function as time to perform these tasks decreased.

The WMFT data are consistent with previous investigations showing that CIT is effective in improving UE motor function as assessed by clinical rating scales,¹³⁻¹⁵ whereas the FMA data are not as clear. The overall reduction in time to perform the WMFT, in particular, the key-turning, was dramatic for 4 of the 5 CIT patients. These data suggest that CIT leads to an improvement in distal UE function of the hemiparetic limb. Improved hand function of the more affected limb of stroke patients is encouraging and may lead to CIT being embraced as a technique for improving the motor performance of stroke patients. To our knowledge, these are the 1st data that provide evidence for improvement in the dexterous abilities of patients with stroke following CIT.

Despite promising reports of CIT improving UE motor function,^{7,13} little is known regarding the mechanism(s) underlying improvements in motor function. Our data suggest that CIT led to a reduction in force variability for this type of dexterous task. The impulse-variability theory assumes that movements are programmed and that the variability in the forces produced and in the durations over which these forces are applied are the major determinants of the variability of limb trajectory.^{16,17} Based on our pretest data, patients in both groups produce highly variable and irregular grasping forces during key-turning. However, after CIT, 4 of the 5 patients were able to decrease the variability of their digit forces and 2 of these patients exhibited modulation of grasping forces. The consistency of the force-rate profiles across trials for those patients who modulated their grasping forces suggests that they were able to reduce the overall variability of digit forces and the duration necessary to apply these forces. A possible mechanism responsible for improved dexterous ability after CIT is improved control of muscle force. CIT may lead to a generalized improvement in the control of forces, as patients in the CIT group improved performance on the key-turning task even though this task was not part of the CIT training activities. Greater consistency and predictability in the control of forces could result in patients utilizing more of a preprogramming or feed-forward movement control strategy. Our data suggest CIT may allow patients to utilize more of a preprogramming movement control strategy, because the rate of force production was greater and more consistent, and movement time to perform UE tasks tended to decrease after the CIT intervention.

In a review of the strength training literature related to the rehabilitation of stroke patients, Ng and Shepherd¹⁸ suggested that strength directly relates to functional improvements in stroke patients. Daily tasks do require a minimum amount of strength for their performance; if individuals lack adequate strength levels, then performance will certainly be impaired.

The current data suggest that absolute strength is not a predictor of dexterous ability. One patient (pt. 8) in the immediate group showed nearly a 128% gain in maximum force production (15.4 N to 35.1 N) from pre- to posttesting sessions. This patient had the greatest maximum precision grip of patients from either group. Even with these impressive strength gains, this patient could not perform the key-turning task in either the pre- or posttest sessions. Furthermore, despite a large overlap in maximum strength levels between groups, the delayed group produced irregular and inconsistent forces and torques during key-turning. Successful performance of daily activities does require a minimum force. However, these data indicate the ability to control muscle forces with precision is of greater importance for the performance of fine motor activities involving the distal musculature, such as turning a key in a lock, than maximum strength levels, especially if one has sufficient strength to perform a given task.

A recent study investigating the effects of stroke on the control of grasping forces highlighted the need to use precise objective and quantitative measures when attempting to understand the effects of stroke on hand function.¹¹ Although patients with stroke were able to transport and cycle objects throughout space, they produced excessive grip forces, relative to healthy controls, during the performance of these actions.¹¹ Excessive grip force or “safety margin” has been suggested to contribute to diminished hand function of older adults^{19,20}; it is reasonable to suggest that this lack of precision in the control of grasping forces in older adults also contributes to their decline in dexterous function. In the current study, the modifications and fabrication procedures for implementing the force transducer into the key required a modest amount of effort. Data collection and analyses programs were easily created with LabView and MatLab software. The force and torque data gathered during this well-practiced functional activity allows for an objective and quantitative assessment of how stroke affects hand function. Accurate measurement of grasping forces provides a more complete picture of specific movement parameters that may be impacted by a therapeutic intervention, such as CIT. A clearer understanding of what movement parameters are changing and the nature of their change can provide insights into the mechanisms responsible for improved motor performance as a result of a given intervention. Future studies interested in the effects of stroke and rehabilitation interventions on hand and UE function should consider employing objective biomechanical measures that capture the dynamic control properties of the movement in addition to maximum strength measures.

The absence of kinematic data in the current study is a limitation, as estimates of key position had to be made. The grasping force and torque data collected during the pretest sessions were so irregular that estimating key position was impossible. As grasping force production improved for the immediate group, identifying the extreme positions of the key was possible based on changes in force magnitude. Collecting position data from the entire UE, trunk, and key would allow for a more complete understanding of how these key-turning movements are controlled. Kinematic measures would provide insight into how stroke affects the control of multiple degrees of freedom of the limb and trunk and how CIT affects the control of the proximal and distal degrees of freedom. Larger scale follow-up studies are planned to examine these issues systematically. Nevertheless, the change in rate of grip force production and modulation of grip forces in 3 of the 5 patients undergoing CIT were evident and suggest that CIT is improving digit force production. To further understand the effects of stroke and CIT on structure-function relationships with respect to the control of grasping forces, efforts should be made to collect data from a more homogeneous patient group in terms of lesion location. Future studies are planned to investigate the persistence of changes in force control in subacute stroke patients undergoing CIT and how the group of chronic patients respond to CIT in term of force control.

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Figure 1.

Illustration of participant grasping the force/torque transducer with the key in the neutral position. The cross-hatch arrow represents initial transducer position (1), solid arrow represents the clockwise turn of the key to the 90-degree position (2), and the open arrow represents the counterclockwise turn to the 90-degree position (3). Figure B depicts the forces and torques about each axis that were being measured. Figure C contains representative grasping force and torque data from a healthy control participant while performing the key-turning task.

Figure 2.

Representative grasping force (grip = solid lines; load = dotted lines) and torque profiles (Tx = solid lines; Ty = dotted lines) for an individual trial for 2 patients in the immediate group (upper plots) and 2 patients (lower plots) in the delayed group during the pretest session.

Figure 3. Representative grip and load forces and torque profiles for an individual trial from the posttest session for the same patients shown in Figure 2.

Figure 4. Representative grasping forces (grip = solid lines; load = dotted lines) for an individual trial for 2 patients in the immediate group after constraint-induced therapy (CIT) completion.

Figure 5.

Individual rate of grip force profiles from grip force onset to completion of key-turning for a patient in the delayed (left plots) and immediate group (right plots) under pre- and posttest conditions.

Table 1

Patient Demographics and Clinical Data

Patient #	Sex	Age	Months Poststroke	Infarct Location	Group	FMA Pre/Post (% change)	WMFT Key-Turning (s) Pre/Post (% change)	WMFT Total (s) Pre/Post (% change)	Preload Time (ms) Pre/Post (% change)
1	F	66	7	Right MCA Cortical	D	34/39 (14.7)	121/121 (0.0)	45.9/47.9 (4.5)	415/366 (-11.8)
2	F	59	6	Right MCA Cortical	D	40/41 (2.5)	44.5/74.6 (67.6)	38.8/31.6 (-18.5)	451/604 (33.9)
3	M	67	6	Right Posterior Cortical	D	61/61 (0.0)	4.3/4.5 (3.9)	11.1/10.5 (-5.5)	119/404 (239.5)
4	M	84	6	Left Cerebellum	D	63/61 (-3.2)	5.5/5.8 (5.5)	2.7/3.4 (23.8)	843/513 (-39.1)
5	M	41	3	Right MCA Cortical	D	29/31 (6.9)	121/121 (0.0)	25.6/31.7 (23.9)	387/452 (16.8)
6	F	69	7	Left Basal Ganglia	I	44/49 (11.4)	6.37/4.51 (-29.1)	15.1/6.2 (-58.9)	550/216 (-60.7)
7	F	56	6	Right Cortical	I	22/26 (18.2)	121/14.9 (-87.6)	69.8/33.03 (-52.7)	121/202 (66.9)
8	M	69	8	Right Parietal Cortical	I	35/30 (-14.3)	121/121 (0.0)	75.7/64.6 (-14.7)	104/311 (199.0)
9	F	74	6	Right CVA Interior Capsule	I	40/38 (-5.0)	10.75/5.85 (-45.6)	4.1/4.4 (6.5)	637/475 (-25.4)
10	M	56	5	Right Basal Ganglia	I	31/38 (22.6)	50.6/14.0 (-72.2)	45.1/36.2 (-19.8)	558/161 (-71.1)
Delayed average change						4%	15%	6%	48%
Immediate average change						7%	-47%	-28%	22%

Patients were randomly assigned to the delayed (D) and immediate (I) groups; consecutive numbering was done post hoc. WMFT = Wolf Motor Function Test; FMA = Fugl-Meyer Assessment Test; MCA = middle cerebral artery; CVA = cerebrovascular accident.