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合併制動療法對中風後上肢功能表現之運動學分析

Combined Restraint Therapy for Improving Upper-Limb Functional Performance after Stroke: A Kinematic Analysis

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中文摘要

背景：中風病患傾向增加使用中風後遺留的動作功能以完成動作任務中之活動要求。最常見的情形為在進行伸手取物時，使用過多的軀幹前屈代償動作。然而，代償動作容易造成病患出現疼痛、不適與關節攣縮等情形；更會阻礙正常的動作形式之復原。在中風後的上肢復健方面，目前已有大量的研究證實制動療法（亦稱為侷限誘發治療）能夠有效地改善上肢動作功能。但另有研究指出此療法可能造成病患較易使用代償動作以完成活動。本研究以運動學分析探討分散式侷限誘發治療合併軀幹侷限，對於中風病患上肢動作控制表現之影響。

方法：本研究採取隨機對照試驗之方法，由醫院之復健部門募集共 18 名慢性中風病患。參與者被隨機分派至分散式侷限誘發治療合併軀幹侷限組與分散式侷限誘發治療組。兩組皆接受由職能治療師所給予的等量治療介入，每天 2 小時，每週 5 天，共為期 3 週。在治療介入前後，利用運動學分析評估患側上肢之動作表現。

結果：合併治療組在治療後相較於分散式侷限誘發治療組有較大的手肘伸直角度，以及較小幅度的軀幹前屈代償動作。在執行雙手伸臂按鈴動作時，合併治療組同時也表現出較佳的上肢關節間協調度。在肩前屈角度與手臂-軀幹間協調的部分，兩組間則無顯著差異。

結論：相較於分散式侷限誘發治療，合併療法較可改善中風病患患側之上肢動作控制策略，使個案表現出較大的主動動作角度，與較少的軀幹前屈幅度。運用此合併療法能夠有效地增加上肢關節間協調，並同時減低中風病患之軀幹代償動作。

關鍵字：腦血管疾病、復健、運動學分析、制動療法、軀幹侷限

Abstract

Background: After stroke, patients make increased use of the redundancy of motor system to acheive the goals of motor tasks. Trunk anterior displacement is a common compensatory movement used by stroke patients for arm transport during reaching. However, the presence of compensatory movements is associated with pain, discomfort, and joint contractures. It also limits recovery of “normal” motor pattern of the affected arm. Numerous studies have provided strong evidence that constraint-induced therapy (CIT), or distributed/modified CIT can improve the function of the affected hand. A previous study suggested that CIT may encourage patients to generate movement through synergy-dominated compensatory movement. The aim of this present study is to determine whether dCIT combined with trunk restraint lead to better motor control performance as reflected by kinematic variables.

Methods: We employed the randomized controlled design. 18 chronic stroke patients were recruited into this study from the rehabilitation departments of participating hospitals. Patients were individually randomized into the dCIT combined with trunk restraint (dCITRes) or the dCIT groups. Each patient received treatment of equal intensity for 2 hours on weekdays for 3 weeks under direct supervision of the occupational therapists. The kinematic analyses were administered before and after the 3-weeks intervention period.

Results: The dCITRes group showed a greater elbow extension and less trunk flexion than those in the dCIT group. Patients in the dCITRes group also showed a greater increase in interjoint coordination of reaching during bimanual task. There was no significant group difference in the normalized shoulder flexion angular change and arm-trunk coordination in this research.

Conclusions: This study provided evidences that there were greater improvements in motor control during reaching movement after dCIT combined with trunk restraint therapy than after dCIT. Patients who received this combined therapy exhibited more active range of motion of UE, less abnormal compensatory movement of trunk and better interjoint coordination than those receiving dCIT. Utilizing this combined therapy may be an effective approach for regaining interjoint coordination of the affected upper extremity and avoiding trunk compensation.

Key words: Cerebrovascular accident, Rehabilitation, Kinematics, Constraint-induced therapy, Trunk restraint

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CHAPTER 1

Literature Review

The Movement Patterns for Reaching in Stroke Survivors

To perform goal-directed actions, individuals must perceive affordances, which mean whether relevant properties of the environment can support the intended actions. Reaching distance is one most common affordance (Mark et al., 1997). According to Fitts' Law, the index of difficulty (ID=$\log_2$ [2D/W]) describes the difficulty to achieve the task: the greater distance for reaching the target, the difficulty of the task increases (Fitts, 1954). As reaching distance increases, individuals recruit additional degrees of freedom (*df*) by leaning forward or twisting at the waist to perform the task. When healthy individuals reach for the target located within 90% arm length, they use only arm extension to accomplish the movement. As the distance increases more than 90% arm length, healthy individuals uses the upper trunk to lean forward. The distance as 90% arm length is called critical boundary (Mark et al., 1997). When healthy individuals reach, whenever the trunk involved, there is a stereotyped sequential recruitment of the arm and trunk in that the trunk begin moving simultaneously with or before the hand and stop moving after the end of hand movement (Kaminski, Bock, & Gentile, 1995).

The use of the trunk for reaching movement in stroke survivors

Trunk anterior displacement is a common compensation movement used by patients with hemiparesis for arm transport during reaching, and for hand orientation during grasping

(Cirstea & Levin, 2000; Michaelsen & Levin, 2004). When stroke patients reached, the contribution of the trunk movement to the endpoint displacement was substantially higher than healthy individuals and occurred earlier in the reach (Levin, Michaelsen, Cirstea, & Roby-Brami, 2002).

Deficits in interjoint coordination of reaching in stroke population

The previous findings indicate that shoulder and elbow motion is strongly coupled (Soechting & Lacquaniti, 1981). After stroke onset, the extensor or flexor synergy has been disrupted, and the interjoint coordination of stroke patients have been affected (Levin, 1996). In addition, the range of active joint motion decreases significantly. Arm movements in stroke subjects were longer, more segmented, more variable and had larger movement errors (Cirstea & Levin, 2000). Furthermore, it was found that patients' motor performance significantly correlated with the level of motor impairment. Patients with severely to moderately motor impairment recruited new degrees of freedom to compensate for motor deficits while mildly impaired patients tended to employ healthy movement patterns (Cirstea & Levin, 2000).

Summary

Following a stroke, the trunk presence excessive movement and the affected arm show poor interjoint coordination while reaching. To develop a more effective rehabilitation protocol, prevention of compensatory trunk movement and facilitation of shoulder-elbow coordination should be more concerned. Therefore, the recovery could be a restoration towards “normal” movement pattern.

The Applications of Trunk Restraint on Upper Extremity (UE) Rehabilitation after stroke

The effects of practice with trunk restraint

Previous research suggested that patients reached under trunk restraint during reaching, the ranges of elbow and shoulder joint increased significantly in distance of full arm’s length than half arm’s length. Trunk restraint profoundly altered the abnormal pattern of interjoint coordination; the underlying “normal” patterns of movement coordination may not be entirely lost after stroke (Michaelsen, Luta, Roby-Brami, & Levin, 2001).

Effects of trunk restraint combined with upper extremity training protocols

Evidence suggested that patients practiced reach-to-grasp movements with trunk restraint harness, after 60-trial training, patients who practiced with trunk restraint used more elbow extension, less anterior trunk displacement, and had better interjoint coordination immediately. The increasing of range of motion was maintained after 24 hours (Michaelsen & Levin, 2004). Researchers extended the reach-to-grasp training protocol to 3 times/week for 5 weeks, trunk restraint group showed more improvement and function than control group, which practiced without physical restraint harness. The improvements were accompanied by increased active joint range, particularly found in more severe patients (Michaelsen, Dannenbaum, & Levin, 2006). Another study utilized reach-to-grasp training combined with trunk restraint reported that after accepted training 2 times per week for 10 weeks, the participants exhibited more improvement than the control group. The improvement was found in FMA, including the aspects of pain, flexor synergy, proprioception, wrist motion, coordination velocity, and total scores (de Oliveira, Cacho, & Borges, 2007).

Recent evidences mentioned that task-related reaching training combined with trunk restraint was found to improve the path of hemiparetic UE while reaching than the resistive exercise combined with trunk restraint. After 4 weeks intervention, both group exhibited motor recovery, but only the task-related reaching training group shown more precision reaching movement than during the resistive exercise group (Thielman, Kaminski, & Gentile, 2008).

Woodbury and colleagues (2009) investigated the effect of CIT combined with trunk restraint in poststroke patients. Compared with CIT group, the combined therapy demonstrated straighter reach trajectories and less trunk displacement. The combined therapy group exhibited more active ranges of motion of shoulder flexion and elbow extension, but the CIT group did not. However, as stated by these researchers, the sample size was insufficient. The functional and table height task has not been performed in kinematics analysis. Furthermore, no work has been done on changes measurement in health-related quality of life (HRQOL) and participation performance through self-report.

Summary

Trunk restraint during rehabilitation of reaching may be an effective therapeutic strategy in patients with moderate-to-severe hemiparetic patients, especially combined with task related training. CIT is not only a task-related therapy, but it also utilizes structured shaping techniques. To prevent compensatory trunk movements and promote UE interjoint coordination may enhance the efficacy of UE rehabilitation, and may encourage the development of the “normal” reaching pattern. When choosing the outcome measures, quality of life, participation performance of patient through self-report should be take into account.

Introduction of Constraint-Induced Therapy (CIT)

Theory background

CIT is one of a few evidence-based neurorehabilitation treatments developed directly from basic science research, the fundamental theoretical constructs of which were subsequently applied to humans (Wolf, Blanton, Baer, Breshears, & Butler, 2002). Researchers noted that after unilateral lesions of the pyramidal tracts, monkeys would fail to use the affected limb and learned compensatory techniques with the less affected arm, this phenomenon Taub and colleagues referred to as learned nonuse (Taub, Goldberg, & Taub, 1975; Tower, 1940).

CIT includes three components: (1) massed practice of more-affected arm for 6 hours per day, 5 days for 2 weeks; (2) patients' less-affected upper limbs are restricted during 90% of waking hours in the 2 week period; and (3) shaping behavior in the training tasks was given to the more-affected arm. "Shaping" refers to a "specific behavioral training technique in which a desired motor or behavioral objective is approached in small steps and increases level of difficulty according to patients' ability (Taub & Wolf, 1997).

The two primary mechanisms proposed for the effects of CIT are believed to be overcoming learned nonuse of the affected limb or use-dependent cortical reorganization. (1) Overcoming learned nonuse phenomenon of more affected limb. Evidence suggested that the ultimate goal of maximum functional recovery should be expressed as lack of dependence or use of these compensatory strategies (Lettinga, 1999). CIT, for overcoming learned nonuse, is achieved through restraint of the less-affected limb, forcing use and reinforcing through the application of shaping or repetitive task practice approaches. (2) Use-dependent cortical reorganization. The potential for reorganization in the adult brain has been largely underestimated (Rossini & Pauri, 2000). Studies involving CIT represented the issues regarding the interaction between behavioral and neural plasticity have been examined. The notion that practice induces plastic and dynamic changes in the CNS is a common belief, even though simple repetition of movement can induce some cortical changes. Several possible mechanisms were proposed including synaptogenesis, dendritic arborisation, unmasking, sprouting, diaschisis, and long-term synaptic potentiation (Rossini, Calautti, Pauri, & Baron, 2003; Taub, Uswatte, & Elbert, 2002).

Applications of CIT in stroke survivors

Numerous researches have provided strong evidences that CIT facilitated recovery significantly. A number of experiments applied CIT on acute, subacute, and chronic stroke patients showed great improvement (Dromerick, Edwards, & Hahn, 2000; Grotta et al., 2004; Taub et al., 1993). Changes in motor function and daily living are usually evaluated, FMA has been utilized in many studies (Lin, Chang, Wu, & Chen, 2008). Arm Research Arm Test (ARAT) (Dromerick et al., 2000), WMFT (Tarkka, Pitkanen, & Sivenius, 2005), and Nine

Hole Peg Test (NHPT) have been used in previous studies. Improvement in daily function assessed by MAL in many experiments, CIT patients reported improvement in the use and function of their affected hand. These findings suggested that the learned nonuse phenomenon can be overcome through CIT. Some other researches used Barthel Index (BI) (Dromerick et al., 2000) or Functional Independent Measure (FIM) (Lin et al., 2008) to investigate independent capability of ADL; or utilized Stroke Impact Scale (SIS) to measure quality of life and participation performance through self-report. Patients receiving CIT demonstrated more improvement, especially in the emotion domain (Wu, Chen, Tsai, Lin, & Chou, 2007).

Kinematic analysis is a high sensitive tool to capture the spatiotemporal characteristics of movement. Several current researches have combined kinematics analysis and clinical outcome measures to investigate patients' performance after receiving CIT (Wu, Chen, Tang, Lin, & Huang, 2007; Wu, Lin, Chen, Chen, & Hong, 2007). The evidence showed after CIT intervention, patients has been reported better motor planning, control strategies, smoother and straighter reaching trajectories (Wu, Chen, Tang et al., 2007; Wu, Lin et al., 2007). Movement kinematics objectively reflected that patients received CIT demonstrated greater motor recovery.

Different forms of constraint-induced therapy (CIT)

According to Page and colleagues (Page, Levine, Sisto, Bond, & Johnston, 2002), there were some difficulties to apply CIT in the clinical setting. The duration for wearing restraint device and taking treatment (6 hour/day) may be difficult to be accomplished. And 83% patients preferred to alternate protocol with the same benefits. Therefore, Page and colleagues brought up a modified CIT (mCIT) protocol that the more-affected side received an hour of occupational and physical therapies (30 minutes for each) per day, three sessions per week for 10 weeks, and restrained less-affected limb for five hours per day, 5 days per week (Page, Levine et al., 2002). A volume of research has estimated the efficacy of mCIT suggested that decrease of treatment duration and restraint and increase of treatment period were also helpful to movements and tasks performance (Page, Sisto, Johnston, & Levine, 2002; Page, Sisto, Levine, & McGrath, 2004; Page, Sisto, & Levine, 2002; Page, Sisto, Levine, Johnston, & Hughes, 2001).

Distributed CIT has been used in recent researches. The protocol including more-affected side received 2 hours training per day, 5 sessions per week for 3 weeks, and restrained less-affected limb for at least 6 hours per day. Several studies have demonstrated the benefits of distributed CIT, relative to traditional rehabilitation or control intervention in improving motor capacity, functional performance, and quality of life (Wu, Chen, Tang et al., 2007; Wu, Chen, Tsai et al., 2007; Wu, Lin et al., 2007).

Summary

Constraint-induced therapy is one of a few evidence-based neurorehabilitation treatments developed directly from basic science research. Numerous studies have demonstrated the benefits of CIT or its derivatives. Nevertheless, CIT has not focused on preventing compensatory movement but reinforcing motor recovery. For instance, recent studies suggested that compensated shoulder abduction increased after CIT intervention (Massie, Malcolm, Greene, & Thaut, 2009). This outcome highlights the need to develop CIT further as an intervention that improves functional capability and more normative movement strategies.

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CHAPTER 2

A Kinematic Study of Distributed Constraint-Induced Therapy Combined with Trunk Restraint in Patients with Stroke

Introduction

After stroke onset, approximately 30% to 60% stroke survivors experience persistent impairment of arm movement (van der Lee et al., 1999). As a result of hemiparesis, stroke patients may progressively avoid using their affected arm in daily activities, resulting in a learned nonuse phenomenon (Grotta et al., 2004). Numerous studies have provide strong evidence that constraint-induced therapy (CIT), distributed or modified forms of CIT can improve the function of the affected hand during performing daily activities and overcome the learned nonuse phenomenon (Page, Sisto, Johnston, & Levine, 2002; Page, Sisto, Levine, & McGrath, 2004; Page, Sisto, & Levine, 2002; Taub et al., 1993; Taub, Uswatte, & Elbert, 2002; Taub & Wolf, 1997; Wu, Chen, Tang, Lin, & Huang, 2007; Wu, Chen, Tsai, Lin, & Chou, 2007; Wu, Lin, Chen, Chen, & Hong, 2007). The specific techniques of CIT include restraint of the less affected UE over an extended period, in combination with intensive task-specific training of the affected limb (Taub, Uswatte, & Elbert, 2002). However, a previous study suggested that CIT may encourage patients to generate movement through synergy-dominated compensatory movement rather than encourage normalization of motor control (Massie, Malcolm, Greene, & Thaut, 2009). Besides, CIT protocol does not aim to improve interjoint coordination but requires patients to increase the amount of forward reaching. The training protocol may have limited the improvement of patients’ ability to recruit both shoulder and elbow muscle groups (Massie et al., 2009).

After stroke, patients increased use of the redundancy of motor system, such as recruiting excessive trunk movement and using shoulder abduction during reaching, and then the interjoint coordination of the affected arm was disrupted and the range of active joint motion was decreased significantly, (Cirstea & Levin, 2000; Ellis, Sukal-Moulton, & Dewald, 2009; Roby-Brami, Fuchs, Mokhtari, & Bussel, 1997). A critical boundary is defined as the distance as 90% arm length (Mark et al., 1997). When healthy individuals reach for the target located within 90% arm length, they use only arm extension to accomplish the movement. As the distance extend more than 90% arm length, healthy individuals use the upper trunk to lean forward. For example, trunk anterior displacement is a common compensation movement used by stroke patients for arm transport during reaching (Michaelsen & Levin, 2004). Stroke patients recruit excessive trunk movement even the target located in the edge of critical boundary (Levin, Michaelsen, Cirstea, & Roby-Brami, 2002). The presence of compensatory movements is associated with pain, discomfort, and joint contractures (Ada, Canning, Carr, & Kilbreath, 1994), and most importantly, it will also obstruct the recovery of "normal" motor patterns of the affected arm (A. Roby-Brami et al., 2003). Previous studies suggested that the unrestricted and unguided repetition of motor tasks may reinforce compensatory movements (Cirstea, Ptito, & Levin, 2003; Michaelsen & Levin, 2004). Thus, to develop an intervention which can prevent abnormal compensatory movement has becoming a critical issue for upper extremity (UE) rehabilitation.

Previous studies reported that after receiving short term reach-to-grasp training combined with trunk restraint, stroke patients demonstrated greater active range of shoulder flexion, elbow extension angle, less anterior trunk displacement and better shoulder-elbow coordination compared with trunk unrestricted (Michaelsen & Levin, 2004). To extend this finding, Michaelsen et al (2006) suggested that chronic stroke patients who trained by reach-to-grasp movement with trunk restraint compared with those without trunk restraint, after a 5 weeks training protocol, patients showed similar results to short term training, especially in patients with moderate motor impairment. These findings suggested that chronic stroke patients still had the ability to alter the compensatory movements and perform movements by using efficient motor strategies. Furthermore, research demonstrated that patients used less trunk flexion and larger elbow flexion angles after receiving task-related training and resistive exercise combined with trunk restraint (Thielman, Kaminski, & Gentile, 2008). One recent study has investigated the effects of CIT (6 hours daily training) combined with trunk restraint showed consistent results with previous studies, but the bimanual and table height movement of kinematic analysis had not been assessed, and the sample size was small in the study (Woodbury et al., 2009).

The aim of this present study is to determine whether distributed CIT (dCIT) combined with trunk restraint lead to better motor control performance. We hypothesized that stroke patients receiving distributed CIT (dCIT) combined with trunk restraint, compared to patients receiving dCIT alone, who would exhibit more UE angular change (larger shoulder flexion and elbow extension), less trunk flexion, and better inter-segment coordination (larger correlation between elbow-shoulder and shoulder-trunk)

Methods

Design

In this randomized controlled study. Patients were individually randomized into the dCIT combined trunk restraint (dCITRes) or the dCIT groups (Fig 1). The kinematics analyses were administered before and after the 3-weeks intervention period. The order of the kinematic analysis assessment was randomized to wash out the order effects.

Participants

We recruited 18 chronic stroke patients (17 men, 1 women; mean age, 53.72) from the rehabilitation departments of 4 participating hospitals. All patients signed informed consent forms approved by the Institutional Review Board. At the beginning of the intervention, they were 6 to 38 months (mean: 13.39 months) postonset of a unilateral stroke of ischemic or hemorrhagic type. Except one patient, the others were all right-handed before stroke by self report.

Inclusion criteria were as follows: (1) clinical diagnosis of a first or recurrent unilateral stroke, (2) the ability to reach Brunnstrom stage Ⅲ or above in the proximal and distal part of arm (Brunnstrom, 1970), (3) no serious cognitive deficits (Mini-Mental State examination score ≥ 23) (Brunnstrom, 1970; Teng & Chui, 1987), (4) considerable non-use of the affected arm (amount-of-use score < 2.5 on Motor Activity Log [MAL]) (Uswatte, Taub, Morris, Light, & Thompson, 2006), (5) no excessive spasticity in the affected arm, including shoulder, elbow, wrist, and fingers (Modified Ashworth Scale score $\leqq 2$ in any joint) (Bohannon & Smith, 1987), (6) able to grasp and release a towel on the table (Bonifer, Anderson, & Arciniegas, 2005), (7) no balance problems sufficient to compromise safety; and (8) lack of participation in any experimental rehabilitation or drug studies and absence of use of antispasticity drugs for UE musculature within the past 3 months. The patients who have history of other neurologic, neuromuscular or orthopedic disease were excluded. The data used in this study was collected from a large clinical trial and was shared in other articles.

Intervention

Regardless of allocation, patients received equal treatment intensity (2h/d, 5d/wk, 3 consecutive weeks) supervised by the occupational therapists directly. The intervention was provided at 4 participating hospitals under the supervision of 4 occupational therapists. The treating therapists were trained in the administration of the dCIT protocol by the investigators and completed a written competency test before subject treatment.

Distributed CIT combined with trunk restraint Group (dCITRes): A trunk restraint harness which consisted with trunk, shoulder and pelvic belts attached to the chair was used during 2-hours training session. The patients in dCITRes group focused on the affected UE used in functional tasks which they performed daily under trunk fixed. The functional training tasks were chosen by patients and the therapist (eg, reaching forward to move a cup from one place to another, flipping pages of magazines, drinking soup with a spoon, using a T.V. remote control to switch channels). Shaping and adaptive and repetitive practice techniques were used during the training session. All practicing objects for this group were placed on the edge of the patient’s critical boundary. During the 3-weeks period, the patients constrained the unaffected hand and wrist in a mitt for 6 hours a day.

Distributed CIT Group (dCIT): Except the use of trunk restraint, patients in dCIT group received intervention which resembles dCITRes group. Furthermore, the factor of distances for practicing objects would not be manipulated.

Outcome Measures

Kinematic analysis was been used to evaluate changes in motor control, which was administered before and after intervention period. All the evaluations were provided by three occupational therapists that blind to group allocation.

Kinematic Analysis. The bimanual reaching tasks which involve a bilateral bell pressing movement were administered and patients were instructed to perform the task after a start signal as fast as possible. After a practice trial, 3 trials were performed. During the tasks, patients sat on a height-adjustable chair with seat height set to 100% of the lower leg length, measured from the lateral knee joint to the floor, with the patient standing (Fig. 2). The trunk was unfixed, and the table height was adjusted to 2 inches below the elbow and patients rested his or her hands on the edge of the table.

The reaching distance to the desk bell was standardized to each patient's functional arm length. Functional arm length was defined as the distance from the medial border of the axilla to the distal wrist crease (Wu, Chen, Tang et al., 2007). If the maximum distance the patient could reach was less than the functional arm length, the reaching distance to the target was adjusted to the maximum reachable distance. Only reaching movements of the affected hand were recorded during this task.

A 7-camera motion analysis system (VICON MX, Oxford Metrics Inc., Oxford, UK) was used in conjunction with one personal computer to capture the movement of markers during reaching and to collect 2 channels of analog signals simultaneously. Reference markers were placed on 7th cervical vertebrae (C7), 4th thoracic vertebrae (T4), clavicle, midsternum, acromion, middle of humerus, lateral epicondyle, styloid process of the ulna and radius, thumb and index nail (Fig 2). Movement onset was defined as a rise of tangential wrist velocity above 5% of its peak value for both of testing tasks, and the offset was defined as the time when the participant pressed the desk bell.

Data Reduction for Kinematic Variables

Movements were recorded at 120 Hz and digitally low-pass filtered at 5 Hz using a second-order Butterworth filter with forward and backward pass. An analysis program coded by LabView language will be use to process the kinematics data. Kinematic variables for active range of motion included normalized shoulder flexion and normalized elbow extension.

1. Normalized shoulder flexion:

The body segments of upper arm and forearm were defined by reference markers, the angular change of shoulder flexion in the sagittal plane throughout the movement would be normalized by the direct distance of arm and target in each participant (Woodbury et al., 2009).

2. Normalized elbow extension:

The extension angular change of elbow joint which were normalized by the direct distance of arm and target in each participant was calculated (Michaelsen, Dannenbaum, & Levin, 2006; Michaelsen & Levin, 2004; Michaelsen, Luta, Roby-Brami, & Levin, 2001; Thielman et al., 2008; Woodbury et al., 2009).

The trunk flexion angular change was normalized by the direct distance of trunk movement represented the variable of trunk involvement. The inter-segment coordination variables involved shoulder flexion-elbow extension correlation and trunk flexion-shoulder flexion correlation. The correlation between angular changes of each segment at every moment in time throughout the movement which was refers to the interjoint and arm-trunk coordination. A higher correlation indicates a better coordination, and lower values reflect that the intersegment coordination might be disrupted in stroke patients (Roby-Brami et al., 1997).

Data Analysis

Demographic statistics were computed for each variable included in this research. Analysis of covariance (ANCOVA), controlling for pre-intervention difference was utilized to test whether the CITRes group performs significantly better than dCIT group on the kinematic analysis. To indicate the magnitude of group differences in performance, the effect size $\eta^2 = SS_b/SS_{total}$ was calculated for each dependent variable. A large effect is represented by a η^2 of at least 0.138, a moderate effect by a η^2 of 0.059, and a small effect by a η^2 of 0.01 (Cohen, 1988). Statistical significance was determined based on one-tailed test with α set at 0.05.

Results

Characteristics of Participants

After being assigned to one of the two groups, 9 participants received dCITRes group and 9 dCIT group. There were no significant differences between the two groups for age, months after stroke, lesion side (left versus right), MMSE scores, MAL scores, or Modified Ashworth Scale of Muscle Spasticity scores. Table 1. shows the demographic and clinical characteristics of participants in the two groups.

Kinematic Analysis

Table 2 displays the statistic results of the dependence variables. ANCOVA showed non-significant and moderate-to-large effect on the kinematic variables of normalized shoulder flexion ($F_{1,15}$=1.652, P=0.109, η^2=0.099). A significant and large effect was found for normalized elbow extension ($F_{1,15}$=3.428, P=0.042, η^2=0.186). The results of ANCOVA showed significant and large effect on the normalized trunk flexion ($F_{1,15}$=3.356, P=0.043, η^2=0.183).

For kinematic variables of the inter-segment correlation, the ANCOVA results showed that shoulder flexion-elbow extension correlation was significantly larger in dCITRes group than in the dCIT group ($F_{1,15}$=7.003, P=0.009, η^2=0.318), but a nonsignificant for trunk flexion-shoulder flexion correlation was found ($F_{1,15}$=0.002, P=0.483, η^2=0.000).

Discussion

In this study, dCIT combined with trunk restraint was associated with better improvement in motor control of reaching than dCIT. The results of the study were partially consistent with the priori hypotheses and notion that dCITRes group showed a greater increase in interjoint coordination of reaching during bimanual task.

Distributed constraint induced therapy combined with trunk restraint patients showed greater elbow extension and less trunk flexion. These findings were consistent with previous studies (Michaelsen et al., 2006; Thielman et al., 2008). In this present study, our result might extend our knowledge of movement pattern improvement of unilateral movement to bimanual. We suggested that after receiving this unilateral motor training, patients may have better performance on the bimanual daily tasks by using less trunk compensatory movement.

In comparison with dCIT, dCITRes group produced better interjoint coordination, our result was consistent with suggestions that chronic stroke patients may regain premorbid movement pattern after appropriate training protocol (Michaelsen & Levin, 2004; Woodbury et al., 2009). A previous research reported CIT training tasks required increase amount of forward reaching, the training may have limited focus on improving the participants' capacity to recruit both shoulder and elbow muscle groups (Massie et al., 2009). Therefore, combined with trunk restraint, dCITRes training protocol could force participants to perform movement by recruiting shoulder and elbow joint without compensatory trunk recruitment, and the improvement of interjoint coordination might related with the increasing of active range of motion (Cirstea & Levin, 2000). Intensive practice with functional tasks under trunk constrained may have provided opportunities for the patients to experience efficient reaching movements and use affected UE with efficiency and coordination (Wu, Chen, Tang et al., 2007). The dCITRes can actually enhance affected upper extremity function of stroke patients by producing remedial effects and not by inducing the trunk compensatory movement to accomplish a functional task.

There was no significant difference between groups in the normalized shoulder flexion angular change in this research. This finding was consistent with previous study, which did not show significantly increase shoulder angular change in the CIT combined with trunk restraint group (Woodbury et al., 2009). In our study, patients of dCITRes group showed a trend of increasing use of shoulder flexion, because patients of dCITRes group might be forced to use their shoulder to complete the task demands (Woodbury et al., 2009). Another possible reason for this result might relate to the kinematics tasks. In our study, participants were instructed to performer a reaching task at table height, and it might be a task of low demands of shoulder flexion. The therapeutic effect on shoulder active range of motion might not be revealed in this kinematics task.

Previous research indicated that the trunk is not only a postural stabilizer for reaching movement, but also integrates the position of hand to close to the target (Kaminski, Bock, & Gentile, 1995). In our study, trunk flexion-shoulder flexion correlation showed no significant differences between groups. A possible explanation for this finding is that while patients who receiving dCIT therapy under trunk restraint, the arm-trunk coordination might be interrupted during training. The improvement of this combined therapy on inter-segment coordination may focus on the aspect of interjoint coordination but not arm-trunk coordination.

Conclusion

In conclusion, this study provided evidence of greater improvement in normalizing movement patterns during reaching movement after distributed CIT combined with trunk restraint therapy. Patients who received this combined therapy exhibited more active range of motion of UE, less abnormal compensatory movement of trunk and better interjoint coordination, and most importantly the movement pattern resembled healthy individuals more after dCITRes versus dCIT. Both distributed CIT and trunk restraint are easy to implement in the clinical setting. Utilizing this combined therapy can be an effective approach for rehabilitation of UE. Future research may investigate the effects of distributed CIT combined with trunk restrain whether improve in motor recovery, functional outcomes, and also motor control strategies while performing functional tasks. Further study may recruit more patients to reinforce the concluded results.

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Table 1. Demographic and clinical characteristics of the participants

	dCITRes (*n* = 9)	dCIT (*n* = 9)	*P**
Gender (male/female)	9/0	8/1	.999
Age (y)	57.67 ± 12.35	49.78 ± 12.56	.198
Months after stroke	10.67 ± 8.82	16.11 ± 9.94	.455
Side of stroke lesion (right/left)	2/7	4/5	.620
Brunnstrom stage of proximal part of UE (median [range])	4 (3-6)	4 (4-6)	.649
Brunnstrom stage of distal part of UE (median [range])	4 (4-6)	4 (4-6)	.331
Modified Ashworth Scale	.44 ± .30	.61 ± .31	.272
Motor Activity Log (amount of use)	.94 ± .68	.70 ± .68	.468
Mini-Mental State Examination	27.00 ± 2.24	27.67 ±1.32	.453

Note. Values are mean ± standard deviation (SD) or as otherwise indicated; dCITRes = Distributed constraint induced therapy combined with trunk restraint; dCIT = Distributed constraint induced therapy.

**P* associated with the Fisher's exact test for categorical variables, with the independent *t* test for continuous variables, and with the Mann-Whitney *U* test for ordinal variables.

Table 2. Descriptive and inferential statistics for analysis of reaching kinematics

	dCITRes (n=9)		dCIT (n=9)		ANCOVA		
	Pretest	Posttest	Pretest	Posttest	$F_{(1, 15)}$	P	η^2
Active range of motion							
Normalized shoulder flexion	1.66 ± 0.45	1.89 ± 0.44	1.89 ± 1.15	1.74 ± 0.82	1.652	0.109	0.099
Normalized elbow extension	1.13 ± 0.77	1.27 ± 0.82	1.03 ± 0.72	0.65 ± 0.89	3.428	0.042*	0.186
Trunk involvement							
Normalized trunk flexion	1.24 ± 0.50	1.14 ± 0.43	0.99 ± 0.51	1.28 ± 0.52	3.356	0.043*	0.183
Inter-segment coordination							
Shoulder-flexion & elbow extension correlation	0.78 ± 0.34	0.93 ± 0.68	0.76 ± 0.45	0.55 ± 0.52	7.003	0.009*	0.318
Trunk-flexion & shoulder flexion correlation	0.82 ± 0.18	0.82 ± 0.12	0.59 ± 0.33	0.69 ± 0.22	0.002	0.483	0.000

Note. Values are mean ± SD or as otherwise indicated ; ANCOVA = Analysis of covariance;

dCITRes = Distributed constraint induced therapy combined with trunk restraint; dCIT = Distributed constraint induced therapy.

* $P < .05$

Figure 1. Flow diagram of the randomization procedure

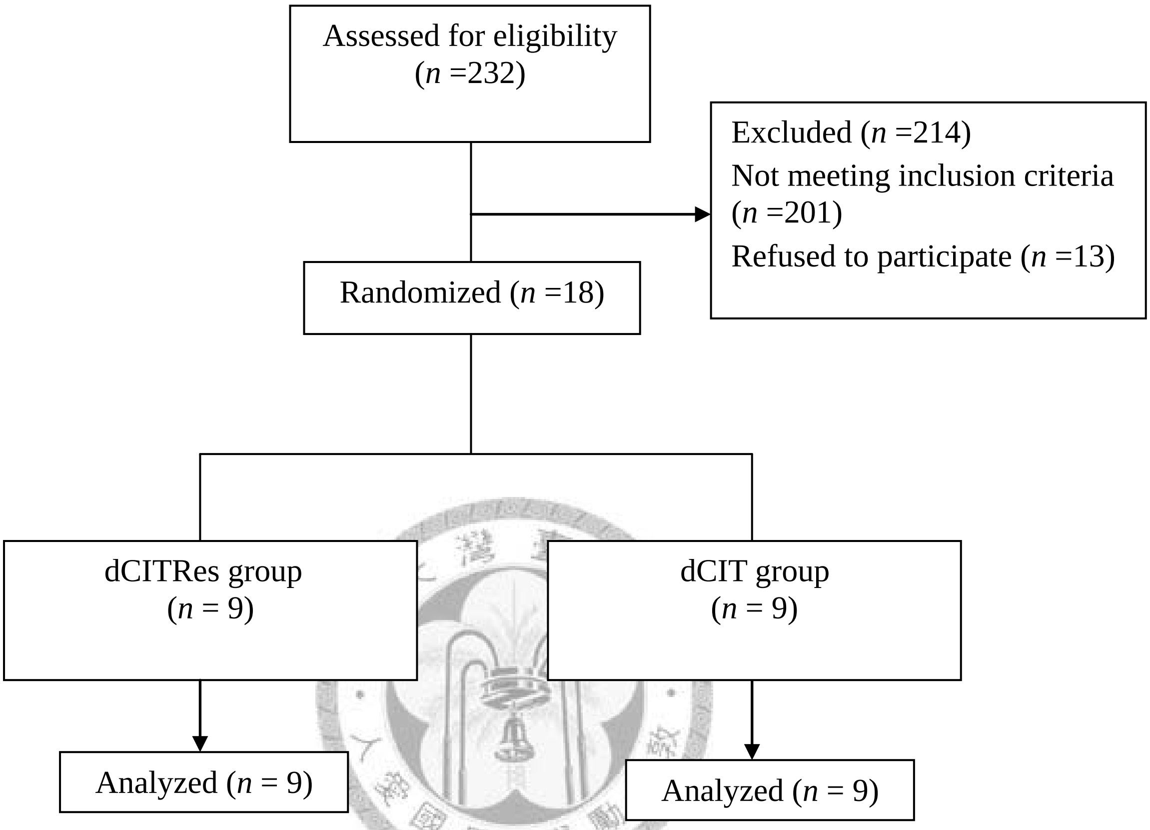
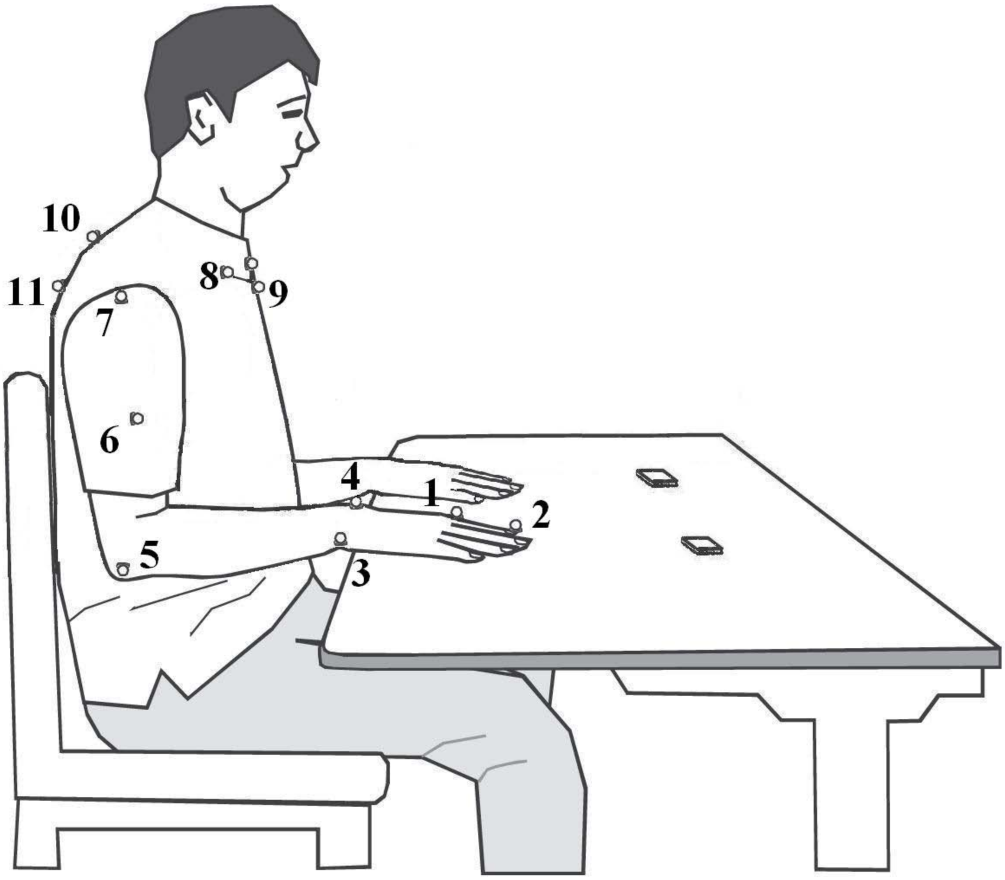


Figure 2. Marker set



Note:

1. Thumb nail
2. Index nail
3. Ulnar styloid
4. Radial styloid
5. Lateral epicondyle
6. Middle of humerus
7. Acromion
8. Clavicle
9. Midsternum
10. C7
11. T4

CHAPTER 3

Effects of Distributed Constraint-Induced Movement Therapy on Movement kinematics and Clinical Outcome in Patients with Stroke: a Randomized Controlled Trial

Introduction

Stroke incidence increases in advanced age, and it is estimated that 75% of strokes occur in elderly patients (Ricauda et al., 2004). Most stroke survivors experienced persistent impairment of arm movement who were unable to use their affected arm in daily activities (van der Lee et al., 1999). Furthermore, the interjoint coordination of the affected arm was disrupted and the range of active joint motion was decreased significantly, arm movements in stroke subjects were longer, segmented, more variable and had larger motor errors (Cirstea & Levin, 2000).

The distance as 90% arm length is called critical boundary, as the reaching distance increases more than the critical boundary, healthy individuals uses the upper trunk to lean forward for getting target (Mark et al., 1997). In contrast, the contribution of the trunk movement to the endpoint displacement was higher in stroke patients and occurred earlier in the reaching period (Levin, Michaelsen, Cirstea, & Roby-Brami, 2002). Moreover, patients increased use of humeral elevation (flexion-abduction) and elbow flexion instead of humeral flexion and elbow extension when reaching forward (Cirstea & Levin, 2000). Studies suggested that when stroke patients reached the targets in the contralateral workspace, who would use trunk rotation more, and the interjoint coordination was decreased in more severe stroke patients (Levin, 1996; Thielman, Kaminski, & Gentile, 2008). Stroke patients relied on the “abnormal” movement pattern while reaching may produce shoulder pain, muscle fatigue and obstruct the recovery of “normal” motor pattern of arm. Rehabilitation protocols of the upper extremity (UE) which can also prevent compensatory movement are needed.

After stroke onset, patients have been encouraged to use their unaffected UE to perform tasks and avoided using the affected UE in daily living progressively. This behavior may result in learned nonuse phenomenon (Grotta et al., 2004). Constraint-induced therapy (CIT) has shown great promise for enhancing UE motor performance and functional use in daily lives (Taub, Uswatte, & Elbert, 2002). The protocol of CIT consist 6 hours of therapy a day for 10 consecutive weekdays while restraining the use of the less affected UE for 90% of waking hours (Dromerick, Edwards, & Hahn, 2000; Taub et al., 1993) . With the success of CIT, modified CIT protocols have been developed (Lin, Chang, Wu, & Chen, 2008; Wu, Chen, Tang, Lin, & Huang, 2007; Wu, Chen, Tsai, Lin, & Chou, 2007; Wu, Lin, Chen, Chen, & Hong, 2007). Although numerous studies have provided strong evidence that CIT or modified forms of CIT can improve the motor performance (eg, increased rating on Fugl-Meyer Assessment [FMA]) and the functional use of the UE (eg, higher score in Motor Activity Log [MAL]) (Lin et al., 2008; Massie, Malcolm, Greene, & Thaut, 2009; Page, Levine, & Leonard, 2005; Page, Sisto, Levine, & McGrath, 2004; Page, Sisto, & Levine, 2002; Page, Sisto, Levine, Johnston, & Hughes, 2001; Taub et al., 1993; van der Lee et al., 1999; Wu, Chen, Tang et al., 2007; Wu, Chen, Tsai et al., 2007; Wu, Lin et al., 2007). Several studies suggested CIT may improve hand function in the Action Research Arm Test (ARAT) and FMA (Page et al., 2005; Page et al., 2004; van der Lee et al., 1999; Wu, Chen, Tsai et al., 2007). Previous kinematics studies investigated the improvement of motor control strategies, the finding demonstrated a higher percentage of movement time where peak velocity occurs (PPV) and shorter movement time (MT) after underwent dCIT (Wu, Chen, Tang et al., 2007; Wu, Lin et al., 2007).

However, a previous study suggested that CIT may encourage patients to generate movement through synergy-dominated compensatory movement rather than encourage normalization of motor control (Massie et al., 2009). Besides, CIT protocol does not aim to improve interjoint coordination but require increase amount of forward reaching, the training may have limited focus on improving the participants' capacity to recruit both shoulder and elbow muscle groups (Massie et al., 2009).

Previous studies reported that reach-to-grasp training combined with trunk restraint, a small sample size of stroke patients demonstrated greater active range of shoulder flexion and elbow extension when compared with trunk unrestricted (Michaelsen, Luta, Roby-Brami, & Levin, 2001). In addition, Michaelsen et al (2006) suggested that chronic stroke patients who trained with trunk restraint compared with those trained without trunk restraint showed greater improvement in shoulder flexion, elbow extension angle and shoulder-elbow coordination, less anterior trunk displacement after a 5 weeks training protocol. These findings suggested that chronic stroke patients still have the ability to alter the compensatory movements and perform movements by using efficient motor strategies. CIT, which incorporates structured a shaping procedure, may enhance the efficacy of trunk restraint to reduce compensatory movements and normalize “abnormal” movements. One recent study has investigated the effects of mCIT combined with trunk restraint showed consistent results with previous study, but the bimanual movement of kinematic analysis has not been assessed, and the sample size was small in this study (Woodbury et al., 2009). Previous studies suggested that after receiving mCIT or reach-to-grasp training combined with trunk restraint, patients showed better interjoint coordination, larger shoulder and elbow angular change. However, the extents to which motor strategies patients adopt under trunk restraint after treatment are still unclear.

In this present research, we hypothesized that both distributed CIT combine with trunk restraint group (dCITRes) and distributed CIT group (dCIT) would elicit better performance than control therapy (CT), patients would exhibit more UE angular change (larger shoulder flexion and elbow extension), less trunk involvement (lesser trunk flexion and trunk rotation), better inter-segment coordination (larger correlation between elbow-shoulder and shoulder-trunk), and better performance on the endpoint control (larger peak velocity, shorter movement time and larger percentage of movement time where peak velocity occurs). In addition, dCITRes and dCIT may achieve greater motor performance and functional gains (higher FMA and MAL scores).

Methods

Design

In this randomized controlled study. Patients were individually randomized into the dCIT combined trunk restraint (dCITRes) or the dCIT or the control therapy (CT) groups (Fig 1). Before and after the 3-weeks intervention period, the kinematics analysis and clinical outcome measures (FMA, MAL) were administered by a blind rater. The order of the kinematics analysis and the clinical outcome assessment was randomized to wash out the order effects, the blinded raters were trained to properly administer these 2 measures.

Participants

We recruited 48 chronic stroke patients (37 men, 11 women; mean age, 53.58) from the rehabilitation departments of 5 participating hospitals. All patients signed informed consent forms approved by the Institutional Review Board. Excepting 2 patients, the others were right-handed before stroke by self report. At the beginning of the intervention, they were 6 to 59 months (mean, 14.85 months; range: 6-59 months) postonset of a cerebrovascular accident of ischemic or hemorrhagic type.

Inclusion criteria were as following: (1) clinical diagnosis of a first or recurrent unilateral stroke, (2) the ability to reach Brunnstrom stage Ⅲ (Brunnstrom, 1970) or above in the proximal and distal part of arm, (3) no excessive spasticity in the affected arm, including shoulder, elbow, wrist, and fingers (Modified Ashworth Scale score ≤ 2 in any joint) (Bohannon & Smith, 1987), (4) considerable non-use of the affected arm (amount-of-use score < 2.5 on MAL) (Uswatte, Taub, Morris, Light, & Thompson, 2006), (5) no serious cognitive deficits (Mini-Mental State Evaluation score ≥ 23) (Teng & Chui, 1987), (6) no balance problems sufficient to compromise safety to wear the constraint device; (7) able to grasp and release a towel on the table (Bonifer, Anderson, & Arciniegas, 2005). Exclusion criteria included history of other neurologic, neuromuscular or orthopedic disease and who participate in any experimental rehabilitation or drug studies. The data used in this study was collected from a large clinical trial and was shared in other articles.

Intervention

Treatment regimens were designed to ensure that patients received equal treatment intensity (2h/d, 5d/wk, 3 consecutive weeks) directly supervised by the occupational therapists. The intervention was provided at 4 participating hospitals under the supervision of 4 occupational therapists. The treating therapists were trained in the administration of the dCIT protocol by the investigators and completed a written competency test before subject treatment.

Distributed CIT combined with trunk restraint Group (dCITRes): A trunk restraint harness which consisted with trunk, shoulder and pelvic belts attached to the chair was used during 2-hours training session. The patients in dCITRes group focused on the affected UE used in functional tasks which they performed daily under trunk fixed. The functional training tasks were chosen by patients and the therapist (ie, reaching forward to move a cup from one place to another, flipping pages of magazines, drinking soup with a spoon, using a T.V. remote control to switch channels). Shaping and adaptive and repetitive practice techniques were used during the training session. All practicing objects for this group were placed on the edge of the patient’s critical boundary. During the 3-weeks period, the patients placed the unaffected hand and wrist in a mitt for 6 hours a day.

Distributed CIT Group (dCIT): Excepting the use of trunk restraint, patients in dCIT group received intervention which resembled dCITRes group. Furthermore, the factor of distances of practicing objects would not be manipulated.

Controlled Therapy (CT): Patients in this group received standard occupational therapy treatment which focused on neurodevelopmental techniques, weight bearing by the affected arm, fine motor dexterity tasks practice, and performed functional tasks by using compensatory strategies.

Outcome Measures

Changes in motor control, motor performance and functional performance of daily living were evaluated using kinematics analysis and clinical evaluation, which were administered before and after intervention period. The evaluations were provided by three occupational therapists that blind to group allocation. Patients were advised not to indicate their treatment assignment to the evaluator.

Kinematic Analysis. One bimanual functional task and two unilateral tasks were administered. During the tasks, patients sat on a height-adjustable chair with seat height set to 100% of the lower leg length, measured from the lateral knee joint to the floor, with the patient standing. The table height was adjusted to 2 inches below the elbow and patients rested his or her hands on the edge of the table. The unilateral task involved pressing a desk bell under trunk restraint or not (Fig 2), and the bimanual task involved using the affected hand to open a drawer and the other hand to retrieve an eyeglass case inside under trunk restraint. Patients were instructed to perform the unilateral task as fast as possible, and performed the bimanual tasks at a comfortable speed. After a practice trial, 3 trials were performed.

The target object was located along the participant’s midsagittal plane, and the reaching distance to the bell and the drawer was standardized to each patient’s functional arm length. Functional arm length was defined as the distance from the medial border of the axilla to the distal wrist crease. If the maximum distance the patient could reach was less than the functional arm length, the reaching distance to the target was adjusted to the maximum reachable distance. Only reaching movements of the affected hand were recorded during this task.

A 7-camera motion analysis system (VICON MX, Oxford Metrics Inc., Oxford, UK) was used in conjunction with one personal computer to capture the movement of markers during reaching and to collect 2 channels of analog signals simultaneously. Reference markers were placed on 7th cervical vertebrae (C7), 4th thoracic vertebrae (T4), clavicles, midsternum, acromion, middle of humerus, lateral epicondyle, styloid process of the ulna and radius, thumb and index nail.

After the start signal rang, participants started to move. Movement onset was defined as a rise of tangential wrist velocity above 5% of its peak value for both of testing tasks. During the unilateral task, movement offset was defined as the time when the participant pressed the desk bell. During the bilateral task, movement offset was defined as a fall of tangential wrist velocity below 5% of its peak value. Movements were recorded at 120 Hz and digitally low-pass filtered at 5 Hz using a second-order Butterworth filter with forward and backward pass.

Clinical Assessments. The FMA and MAL were conducted before and after intervention. The Fugl-Meyer Assessment (FMA) was used to evaluate the level of impairment. The items of the FMA were derived from the Brunnstrom stages of poststroke recovery. This is a 3-point ordinal scale (0 = cannot perform, 1 = can perform partially, 2 = can perform fully), and great test-retest reliability, interrater reliability and construct validity have been shown (Di Fabio & Badke, 1990; Duncan, Propst, & Nelson, 1983). In our study, the 66-points UE section of FMA was used.

The MAL is a semi-structured interview that measure patients' perception of real-world use of the affected arm. It consists of 30 important activities of daily living (ADL). Patients used a 6-point amount of use (AOU) scale to rate the extent of use of the arm and a 6-point quality of movement (QOM) scale to rate how well patients feel they can use the affected arm. The MAL has established good test-retest reliability, internal consistency and convergent validity (Uswatte et al., 2006; Uswatte, Taub, Morris, Vignolo, & McCulloch, 2005; van der Lee, Beckerman, Knol, de Vet, & Bouter, 2004).

Data Reduction for Kinematic Variables

An analysis program coded by LabVIEW language was use to process the kinematics data. Kinematic variables for range of motion involved normalized shoulder flexion angle and normalized elbow extension angle.

1. Normalized shoulder flexion:

The body segments of upper arm and forearm were defined by reference markers, the angular change of shoulder flexion in the sagittal plane throughout the movement was normalized by the direct distance of arm and target in each participant (Woodbury et al., 2009).

2. Normalized elbow extension:

The extension angular change of elbow joint which was normalized by the direct distance of arm and target in each participant was calculated (Michaelsen, Dannenbaum, & Levin, 2006; Michaelsen & Levin, 2004; Michaelsen et al., 2001; Thielman et al., 2008; Woodbury et al., 2009).

The inter-segment coordination variables involved shoulder flexion-elbow extension correlation and trunk flexion-shoulder flexion correlation. The trunk flexion-shoulder flexion correlation was calculated only in the task without trunk restraint. The correlation between angular changes of each segment at every moment in time throughout the movement which were refers to the interjoint and arm-trunk coordination. A higher correlation indicates a better coordination, and lower values reflect the intersegment coordination might be disrupted in stroke patients (A Roby-Brami, Fuchs, Mokhtari, & Bussel, 1997).

The kinematic variables for trunk involvement were calculated in the tasks performed without trunk restraint which involved normalized trunk flexion and trunk rotation. The trunk flexion angular change was normalized by the direct distance of trunk movement. The trunk rotation was defined by the displacement of the acromion of the unaffected side subtracted from C7 in the horizontal plane (Thielman et al., 2008).

The kinematic variables for arm movement included peak velocity (PV), the percentage of movement time where peak velocity occurs (PPV) and normalized movement time (NMT):

1. Peak velocity (PV):

Peak velocity referred to force or impulse at initiation. Higher-amplitude peak velocity indicated greater force or impulse (Nelson, 1983).

2. The percentage of movement time where peak velocity occurs (PPV):

PPV was used to characterize the control of strategy of reaching. It reflected the percentage of movement time for acceleration phase. The acceleration phase was proposed to be the major preplanned aspect of the movement. A higher PPV indicated a longer acceleration phase, suggesting less online error correction and more preplanned control of the reaching movement. The deceleration phase referred to the immediate feedback through the reaching movement, which can help individuals to correct the movement and reach the target. (Haaland, Prestopnik, Knight, & Lee, 2004; Kamper, McKenna-Cole, Kahn, & Reinkensmeyer, 2002)。

3. Normalized movement time (NMT):

The time for execution of the reaching movement was characterized by movement time (MT). It was the interval between movement onset and movement offset, representing temporal efficiency (Wu, Chen, Tang et al., 2007; Wu, Lin et al., 2007). MT was normalized to the distance between arm and target in each participant.

Data Analysis

Demographic statistics were computed for each variable included in this research. Analysis of covariance (ANCOVA), controlling for pre-intervention difference was used to compare 3 groups improvement for each outcome variable. Pre-intervention performance was the covariate, group was the independent variable, and post-intervention performance was the dependent variable. To indicate the magnitude of group differences in performance, the $\eta^2 = SS_b/SS_{total}$ was calculated for each outcome variable. A large effect is represented by a η^2 of at least 0.138, a moderate effect by a η^2 of 0.059, and a small effect by a η^2 of 0.01 (Cohen, 1988). Statistical significance was determined based on one-tailed tests with an α of 0.05. The Fisher’s least significant difference tests were used for post hoc comparisons between groups. Level of statistical significance was set at .05.

Results

Characteristics of Participants

48 patients were recruited in this study. There were no significant differences between the three groups for age, months after stroke, lesion side (left versus right), MMSE scores, MAL scores, or modified Ashworth Scale of Muscle Spasticity scores. Table 1 shows the demographic and clinical characteristics of participants in the two groups. Table 2 shows the descriptive statistics and inferential statistics for each outcome measure. The results were partially consistent with the study hypotheses.

Kinematic Variables: There were differences between the 3 groups in the kinematic variables of normalized active range of motion in bimanual task and unilateral tasks (normalized shoulder flexion of bimanual task: $F(2,39) = 3.575$, $P < .002$, $\eta^2 = .155$; normalized elbow extension of bimanual task: $F(2,39) = 3.646$, $P < .002$, $\eta^2 = .158$; normalized shoulder flexion of restraint unilateral task: $F(2,41) = 3.230$, $P < .03$, $\eta^2 = .136$; normalized elbow extension of restraint unilateral task: $F(2,41) = 2.581$, $P = .04$, $\eta^2 = .112$; normalized shoulder flexion of unrestraint unilateral task: $F(2,42) = 3.616$, $P < .02$, $\eta^2 = .147$). Differences were also found in the kinematic variables of inter-segment coordination in both tasks under trunk restraint (shoulder flexion-elbow extension correlation of bimanual task: $F(2,39) = 5.36$, $P < .005$, $\eta^2 = .216$; shoulder flexion-elbow extension correlation of restraint unilateral task: $F(2,41) = 2.60$, $P = .04$, $\eta^2 = .113$). There were differences between the 3 groups in the kinematic variables of trunk involvement in the unilateral task without trunk restraint (trunk rotation of unrestraint unilateral task: $F(2,42) = 3.996$, $P < .001$, $\eta^2 = .160$) Although there were no group effects on peak velocity, the arm movement variables of the percentage of movement time where peak velocity occurs in the unilateral restraint task were differences between the 3 groups (PPV of restraint unilateral task : $F(2,41) = 5.329$, $P = .005$, $\eta^2 = .206$) Differences were also found in the normalized movement time in the unilateral task without trunk restraint (NMT of unrestraint unilateral task : $F(2,42) = 3.409$, $P = .001$, $\eta^2 = .160$)

Clinical Outcome Measures: There were no differences found in the overall FMA scores, performance on the hand subtest in the FMA was different between the 3 groups: ($F(2, 44) = 5.86$, $P = .019$, $\eta^2 = .139$). Differences were not found in the overall MAL scores but in the amount of use (AOU: $F(2,44) = 3.71$, $P = .016$, $\eta^2 = .144$)

Post hoc analyses

Kinematic Variables: Post hoc analyses revealed that, in comparison with the control treatment group, dCITRes group produced greater normalized AROM change in the bimanual task (normalized shoulder flexion, $P = .03$ for dCITRes vs CT, $P = .008$ for dCITRes vs dCIT; normalized elbow extension $P = .03$ dCITRes vs CT, $P = .007$ for dCITRes vs dCIT). dCITRes group produced greater normalized AROM change in the restraint unilateral task (normalized shoulder flexion, $P = .02$ for dCITRes vs CT, $P = .01$ for dCITRes vs dCIT; normalized elbow extension $P = .03$ for dCITRes vs CT; $P = .01$ for dCITRes vs dCIT). dCITRes group also produced greater normalized shoulder flexion in the unrestraint unilateral task (normalized shoulder flexion, $P = .01$ for dCITRes vs CT).

In the bimanual task, the dCIT group demonstrated greater improvement in interjoint coordination than the CT group ($P = .002$), and the dCITRes group also produced better interjoint coordination than the CT group ($P = .01$). Post hoc analyses revealed that the dCITRes showed greater in interjoint correlation than the CT group in the restraint unilateral task ($P = .02$). In the unrestraint unilateral task, both dCITRes and dCIT group showed less trunk rotation (trunk rotation, $P < .01$ for dCITRes vs CT, $P = .03$ for dCIT vs CT). In the restraint unilateral task, and the CT and dCIT group both produced larger PPV than the dCITRes group (PPV, $P = .01$ for CT vs dCIT, $P = .02$ for dCIT vs dCITRes). Post hoc analyses revealed that the CT and dCIT group both produced shorter normalized movement time than the dCITRes group in the unrestraint unilateral task (NMT, *P* = .03 for dCIT vs dCITRes, *P* = .01 for CT vs dCITRes)

Clinical Outcome Measures: Post hoc analyses revealed that the dCIT group produced greater improvement in the distal score of FMA than dCITRes group (*P* = .01) and CT group (*P* = .01). In the scores of amount of use in MAL, dCIT group showed greater improvement than CT group (*P* = .005), the dCITRes group rated higher amount of use than the CT group (*P* = .04).

Discussion

The findings on motor performance were in a large part consistent with our hypothesis. In agreement with previous research (Michaelsen et al., 2006; Michaelsen & Levin, 2004; Thielman et al., 2008; Woodbury et al., 2009), dCIT combined with trunk restraint demonstrated greater improvement in AROM of shoulder and elbow joint. The dCIT group showed non-significant angular change in shoulder flexion, and this finding was inconsistent with previous studies (Caimmi et al., 2008; Massie et al., 2009). One possible explanation was that our intensity of the intervention was different with which used traditional CIT protocol (Caimmi et al., 2008; Massie et al., 2009). The patients of the previous studies received 6 hours forced use intervention per day, our study utilized dCIT, which patients received 2 hours forced use per day, the amount of constraint hours were different either.

After received dCITRes intervention, patients showed more elbow extension angular change compared with dCIT or CT group, and dCIT demonstrated non-significant improvement in elbow AROM compared with CT group. The results were similar with previous studies reported. Massie et al (2009) suggested that CIT showed no advantages in improving elbow extension range. The finding of our results expanded previous knowledge that patients who received dCIT and controlled therapy showed non-significant improvement in elbow extension even in the condition of reaching movement under trunk restraint.

Compared with CT, both dCITRes and dCIT group improve UE interjoint coordination in the kinematics assessment. Because of the differences in the tasks of kinematic analysis, these results might not be consistent. dCIT group preformed better interjoint coordination in the bimanual task. This finding contrasted with the previous research, which showed a decrease of interjoint coordination in patients who received CIT compared with CIT combined with trunk restraint (Woodbury et al., 2009). In our study, the task conditions of kinematics analysis were different from the previous research. Patients were instructed to use the affected hand to open a drawer and used the unaffected hand to retrieve an eyeglass case. To compare with the controlled therapy group, this kind of functional task may resemble training activities of dCIT and dCITRes. The results demonstrated that dCIT compared with controlled therapy can improve interjoint coordination, especially in the functional task. These data may suggest that qualities of the relearned movement coordination strategy may be influenced by the context of learning (Woodbury et al., 2009). While reaching the unilateral desk bell with trunk restraint, patients in dCITRes group show significant greater interjoint coordination than patients in the controlled therapy group. This finding was consistent with previous studies, the improvement may be produced by increase of active range of motion, and patients who received repetitive practice under trunk restraint may regain premorbid coordination patterns (Cirstea & Levin, 2000; A. Roby-Brami et al., 2003; Woodbury et al., 2009).

Previous study indicated that the interjoint coordination for movement to the targets in the contralateral (near the unaffected side) workspace was decreased in severe stroke patients (Levin, 1996). When stroke patients reached the targets in the contralateral workspace, who would use less trunk flexion and more trunk rotation (Thielman et al., 2008). In our study, patients reached the target located along the midsagittal plane, which were closed to the contralateral workspace. After received intervention, patients in dCITRes and dCIT group showed less trunk rotation than CT group in the unrestraint unilateral task. These results suggested that dCITRes and dCIT compared with controlled therapy can decrease the compensatory of trunk rotation. Patients might use more AROM of affected UE to complete the tasks. The movement pattern of dCITRes and dCIT resembled normal movement pattern more.

The counterintuitive change in arm movement variables of PPV was found. Both dCIT and CT group showed significantly increase of the PPV value compared with dCITRes group.

This finding contrasted with a previous study which showed no significant group difference in the PPV after received a short-term reach-to-grasp training with trunk restraint (Michaelsen & Levin, 2004). The task condition of reaching kinematics was different with previous study and ours. After 3-weeks intervention, our patients performed reaching task under trunk restraint in the posttest but the previous study was not. PPV is used to characterize the control of strategy during reaching. The acceleration phase is proposed to be the major preplanned aspect of the movement, and the deceleration phase refers to the feedback through the reaching movement, which can help individuals to correct the movement and reach the target (Haaland, Prestopnik, Knight, & Lee, 2004; Kamper, McKenna-Cole, Kahn, & Reinkensmeyer, 2002). A higher PPV indicates less online error correction and more preplanned control of the reaching movement.

Woodbury et al (2009) suggested that the “trunk restraint” might be regarded as the knowledge of performance (KP). While leaning forward, patients received the sensory afferent cue from the trunk restraint; the cue was regarded as an external feedback. Our results suggested that after received 3-weeks of intensive treatment, patients might much rely on the KP from the afferent cue of “trunk restraint”. The kinematic assessment of reaching movement under trunk restraint after 3-weeks intervention may expose the actuality. The KP of trunk restraint through the training may be a reason of dCITRes having a trend of having longer movement time. Our results demonstrated that treatment combined with trunk restraint might lead to entirely different outcome.

Previous kinematics studies indicated that dCIT would lead better endpoint control of reaching movement (Wu, Chen, Tang et al., 2007; Wu, Lin et al., 2007). We suggested that dCIT combined with trunk restraint would lead greater active range of motion of UE and better interjoint coordination. This suggestion were consistent with the agreement of previous study (Michaelsen et al., 2006). Patients with severe UE impairment may induce more improvements with trunk restraint. Young and Schmidt (1992) demonstrated that compared with continuous feedback, less frequent feedback may lead more retention of learning. Faded trunk restraint may be used in the future research for better motor control and learning retention (Woodbury et al., 2009). After received intervention, patients in dCIT and CT groups showed shorter NMT than dCITRes group in the unrestraint unilateral task. This finding indicated that patients in the dCITRes group might focus on using the normal movement pattern to complete the task which the longer movement time might be needed.

The greater improvement in the distal part scores of FMA seen in the dCIT group than in CT group corresponded with those of previous study (Page et al., 2005; Page et al., 2004; van der Lee et al., 1999; Wu, Chen, Tsai et al., 2007). The dCIT group showed greater improvement in the scores of distal part in FMA than dCITRes group. The clinical outcome measure used in this study did not identify differences in coordination strategies among individuals with stroke. Patients might use compensatory movement pattern to complete the assessment and achieved higher scores (Woodbury et al., 2009). dCITRes group did not achieve higher score than dCIT group might cause by using more “normal” movement strategies to accomplish the assessment (Woodbury et al., 2009). Previous research suggested there is a need for developing a valid and sensitive measures that can reflect the real movement recovery (Michaelsen et al., 2001).

Both dCIT and dCITRes group showed more improvement in MAL-AOU than the CT group. The result is consistent with previous studies (Lin, Wu, Wei, Lee, & Liu, 2007; Massie et al., 2009; Page et al., 2004; Wu, Chen, Tang et al., 2007; Wu, Chen, Tsai et al., 2007). These significant improvements of MAL-AOU suggested that the learned nonuse phenomenon observed in the patients can be overcome through an intensive training which emphasizing repeated functional use.

Conclusion

The current research suggested that dCIT combined with trunk restraint shows entirely different aspects of motor improvement with dCIT. Future research might investigate the benefits of receiving distributed constraint induced therapy combined with trunk restraint in the instrumental activities of daily living (IADL) and quality of life (QOL).

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Table 1. Demographic and clinical characteristics of the participants

	dCITRes (n = 16)	dCIT (n = 16)	CT (n=16)	$F_{(2,45)}$	P^a
Sex (male/female)	16 (14/2)	16 (11/5)	16 (12/4)		0.572
Age (in years)	55.13 ± 11.08	53.19 ± 12.63	52.44 ± 10.83	0.231	0.795
Onset (months)	17.56 ± 16.26	12.56 ± 5.06	14.44 ± 12.00	0.706	0.499
Side of brain lesion (R/L)	4/12	8/8	9/7		0.191
FMA pre-total	45.38 ± 8.78 (28-61)	46.81 ± 7.71 (34-60)	45.31 ± 7.29 (33-59)	0.182	0.834
MAL-AOU	0.93 ± 0.63	0.91 ± 0.72	1.03 ± 0.90	0.110	0.896
MMSE	26.63 ± 2.25	28.00 ± 1.41	27.38 ± 2.42	1.764	0.183
mASMS	0.43 ± 0.24	0.47 ± 0.31	0.49 ± 0.24	0.256	0.775

Note. Values are mean ± standard deviation (SD) or as otherwise indicated; dCITRes, Distributed constraint induced therapy combined with trunk restraint; dCIT, Distributed constraint induced therapy; CT, controlled treatment; R, right; L, left; FMA, Fugl-Meyer assessment; MAL-AOU, Motor Activity Log-amount of use; MMSE, Mini-Mental State Examination; mASMS, modified Ashworth Scale of Muscle Spasticity. [a]*P* associated with the chi-square test for categorical variables, with the analysis of variance for continuous variables, and with the Mann-Whitney *U* test for ordinal variables.

Table 2. Descriptive and inferential statistics for analysis of bimanual kinematic task

	dCITRes (n = 14)		dCIT (n = 15)		CT (n=14)		Statistics		
	Pretest	Posttest	Pretest	Posttest	Pretest	Posttest	$F_{(2,39)}$	P	η^2
Active range of motion									
Normalized shoulder flexion	1.46 ± 0.46	2.07 ± 0.64	1.51 ± 0.67	1.61 ± 0.56	1.36 ± 0.75	1.64 ± 0.52	3.58	0.02*	0.155
		(2.07 ± 0.14)		(1.57 ± 0.13)		(1.68 ± 0.14)			
								0.03^{A}* 0.01^{B}* 0.30^{C}	
Normalized elbow extension	0.59 ± 0.43	1.14 ± 0.77	0.64 ± 0.56	0.63 ± 0.59	0.58 ± 0.57	0.70 ± 0.56	3.65	0.02*	0.158
		(1.14 ± 0.15)		(0.61 ± 0.15)		(0.72 ± 0.15)			
								0.03^{A}* 0.01^{B}* 0.30^{C}	
Inter-segment coordination									
Shoulder flexion & elbow extension correlation	0.46 ± 0.43	0.66 ± 0.45	0.51 ± 0.35	0.78 ± 0.19	0.44 ± 0.41	0.34 ± 0.53	5.36	0.01*	0.216
		(0.66 ± 0.09)		(0.75 ± 0.08)		(0.37 ± 0.09)			
								0.01^{A}* 0.24^{B} 0.00^{C}*	

Arm movement variables									
PV	576.86 ± 158.86	607.05 ± 126.25 (603.76 ± 24.39)	545.57 ± 148.74	650.19 ± 116.75 (656.61 ± 23.54)	563.93 ± 135.46	612.56±101.74 (618.27± 24.33)	1.305	0.14	0.063
NMT	0.076 ± 0.092	0.067 ± 0.091 (0.061 ± 0.005)	0.064 ± 0.027	0.050 ± 0.015 (0.054 ± 0.005)	0.066 ± 0.038	0.056 ± 0.025 (0.057 ± 0.005)	0.432	0.33	0.022
PPV	33.63±8.89	34.64 ± 14.26 (33.94 ± 2.33)	30.97±9.69	31.03 ± 10.93 (32.81 ± 2.27)	33.66±6.19	31.49 ± 9.26 (30.29 ± 2.34)	0.644	0.27	0.032

Note. Values are mean ± standard deviation (SD); values in bracket are means adjusted for covariate in the ANCOVA model; values in bracket are means adjusted for covariate in the ANCOVA model; dCITRes, Distributed constraint induced therapy combined with trunk restraint; dCIT, Distributed constraint induced therapy; CT, controlled treatment; PV, peak velocity; NMT, normalized movement time; PPV, the percentage of movement time for acceleration path. **P* <.05. The superscript for comparisons between groups: A, distributed constraint induced therapy combined with trunk restraint group versus controlled treatment group; B, distributed constraint induced therapy combined with trunk restraint group versus distributed constraint induced therapy group; C, distributed constraint induced therapy group versus controlled treatment group.

Table 3. Descriptive and inferential statistics for analysis of unilateral restraint kinematic task

	dCITRes (n = 15)		dCIT (n = 14)		CT (n=16)		Statistics		
	Pretest	Posttest	Pretest	Posttest	Pretest	Posttest	$F_{(2,41)}$	P	η^2
Active range of motion									
Normalized shoulder flexion	1.57 ± 0.67	2.08 ± 0.86	1.51 ± 0.85	1.49 ± 0.67	1.79 ± 0.49	1.72 ± 0.69	3.23	0.03*	0.136
		(2.11 ± 0.17)		(1.56 ± 0.17)		(1.63 ± 0.16)			
								0.02^{A}* 0.01^{B}* 0.40^{C}	
Normalized elbow extension	1.08 ± 0.64	1.40 ± 0.58	1.10 ± 0.56	1.12 ± 0.54	1.20 ± 0.53	1.20 ± 0.57	2.58	0.04*	0.112
		(1.44 ± 0.1)		(1.14 ± 0.11)		(1.16 ± 0.1)			
								0.03^{A}* 0.03^{B}* 0.47^{C}	
Inter-segment coordination									
Shoulder flexion & elbow extension correlation	0.60 ± 0.50	0.86 ± 0.23	0.42 ± 0.50	0.71 ± 0.26	0.70 ± 0.34	0.56 ± 0.62	2.60	0.04*	0.113
		(0.85 ± 0.10)		(0.75 ± 0.11)		(0.53 ± 0.10)			
								0.02^{A}* 0.26^{B} 0.07^{C}	

Arm movement variables									
PV	732.30 ± 197.48	767.60 ± 144.35 (772.69 ± 42.11)	750.20 ± 154.55	790.57 ± 222.89 (784.84 ± 43.60)	740.32 ± 172.77	746.27 ± 204.76 (746.52 ± 40.76)	0.22	0.40	0.011
NMT	0.06 ± 0.04	0.07 ± 0.04 (0.07 ± 0.01)	0.06 ± 0.03	0.05 ± 0.04 (0.06 ± 0.01)	0.08 ± 0.08	0.05 ± 0.02 (0.05 ± 0.01)	2.07	0.07	0.092
PPV	29.15 ± 8.98	24.62 ± 9.36 (24.17 ± 2.72)	24.81 ± 9.88	34.44 ± 14.45 (36.56 ± 2.85)	30.83 ± 16.71	34.39 ± 13.90 (32.96 ± 2.65)	5.33	0.01* 0.01^{A}* 0.00^{B}* 0.18^{C}	0.206

Note. Values are mean ± standard deviation (SD); values in bracket are means adjusted for covariate in the ANCOVA model; dCITRes, Distributed constraint induced therapy combined with trunk restraint; dCIT, Distributed constraint induced therapy; CT, controlled treatment; PV, peak velocity; NMT, normalized movement time; PPV, the percentage of movement time for acceleration path. **P* <.05. The superscript for comparisons between groups: A, distributed constraint induced therapy combined with trunk restraint group versus controlled treatment group; B, distributed constraint induced therapy combined with trunk restraint group versus distributed constraint induced therapy group; C, distributed constraint induced therapy group versus controlled treatment group.

Table 4. Descriptive and inferential statistics for analysis of unilateral unrestraint kinematic task

	dCITRes (n = 16)		dCIT (n = 14)		CT (n=16)		Statistics		
	Pretest	Posttest	Pretest	Posttest	Pretest	Posttest	$F_{(2,42)}$	P	η^2
Active range of motion									
Normalized shoulder flexion	1.40 ± 0.54	1.73 ± 0.51	1.50 ± 0.51	1.59 ± 0.53	2.04 ± 1.09	1.55 ± 0.58	3.616	0.02*	0.147
		(1.84 ± 0.11)		(1.65 ± 0.12)		(1.39 ± 0.12)			
								0.01^{A}* 0.13^{B} 0.07^{C}	
Normalized elbow extension	0.62 ± 0.56	0.76 ± 0.49	0.64 ± 0.62	0.89 ± 0.57	1.22 ± 1.21	0.95 ± 0.44	0.300	0.37	0.014
		(0.82 ± 0.11)		(0.94 ± 0.12)		(0.84 ± 0.12)			
Inter-segment coordination									
Shoulder flexion & elbow extension correlation	0.65 ± 0.54	0.85 ± 0.18	0.68 ± 0.31	0.85 ± 0.15	0.88 ± 0.15	0.92 ± 0.08	0.212	0.40	0.010
		(0.87 ± 0.03)		(0.86 ± 0.03)		(0.89 ± 0.03)			
Trunk-flexion & shoulder flexion correlation	0.82 ± 0.10	0.82 ± 0.19	0.67 ± 0.34	0.70 ± 0.31	0.67 ± 0.47	0.75 ± 0.20	0.424	0.33	0.020
		(0.79 ± 0.05)		(0.72 ± 0.06)		(0.76 ± 0.05)			
Trunk involvement									
Normalized trunk flexion	1.04 ± 0.38	1.03 ± 0.61	1.09 ± 0.47	0.94 ± 0.45	0.94 ± 0.84	1.04 ± 0.32	0.347	0.35	0.016
		(1.03 ± 0.12)		(0.92 ± 0.12)		(1.05 ± 0.12)			

Trunk rotation	-9.94 ± 3.32	-6.99 ± 3.13 (-6.50 ± 0.81)	-7.69 ± 4.99	-7.12 ± 2.64 (-7.45 ± 0.845)	-8.02 ± 3.68	-9.41 ± 4.25 (-9.62 ± 0.79)	3.996	0.01 0.00^{A}* 0.21^{B} 0.03^{C}*	0.160
Arm movement variables									
PV	610.01 ± 174.34	639.17 ± 122.40 (651.31 ± 33.98)	679.42 ± 164.19	743.62 ± 160.93 (734.51 ±) 36.18	663.26 ± 211.70	660.52 ± 150.60 (656.36 ± 33.73)	1.727	0.19	0.076
NMT	0.07 ± 0.03	0.08 ± 0.07 (0.09 ± 0.01)	0.08 ± 0.07	0.06 ± 0.04 (0.06 ± 0.01)	0.09 ± 0.08	0.05 ± 0.03 (0.05 ± 0.01)	3.409	0.02* 0.01^{A}* 0.03^{B}* 0.35^{C}	0.140
PPV	29.52 ± 9.64	30.25 ± 18.79 (30.77 ± 3.41)	27.26 ± 13.02	33.97 ± 16.82 (35.95 ± 3.68)	33.85 ± 17.11	31.69 ± 11.97 (29.43 ± 3.45)	0.905	0.20	0.041

Note. Values are mean ± standard deviation (SD); values in bracket are means adjusted for covariate in the ANCOVA model; dCITRes, Distributed constraint induced therapy combined with trunk restraint; dCIT, Distributed constraint induced therapy; CT, controlled treatment; PV, peak velocity; NMT, normalized movement time; PPV, the percentage of movement time for acceleration path. **P* <.05. The superscript for comparisons between groups: A, distributed constraint induced therapy combined with trunk restraint group versus controlled treatment group; B, distributed constraint induced therapy combined with trunk restraint group versus distributed constraint induced therapy group; C, distributed constraint induced therapy group versus controlled treatment group.

Table 5. Descriptive and inferential statistics for analysis of clinical outcome measures

	dCITRes (n = 16)		dCIT (n = 16)		CT (n=16)		Statistics		
	Pretest	Posttest	Pretest	Posttest	Pretest	Posttest	$F_{(2,44)}$	P	η^2
FMA									
Proximal	31.38 ± 5.57	33.75 ± 3.77	32.13 ± 5.10	34.13 ± 3.20	30.06 ± 4.01	33.31 ± 3.91	0.193	0.413	0.009
		(33.64±0.52)		(33.56±0.53)		(33.99±0.53)			
Distal	14.00 ± 5.06	16.50±4.73	14.69 ± 4.49	17.75±4.85	15.25 ± 4.84	18.13±5.06	0.447	0.322	0.020
		(17.11±0.47)		(17.71±0.47)		(17.56±0.47)			
Wrist	4.31 ± 3.11	5.81 ± 2.54	6.00 ± 2.37	6.94 ± 2.46	5.50 ± 2.42	7.38 ± 2.66	1.372	0.132	0.059
		(6.57 ± 0.38)		(6.36 ± 0.38)		(7.20 ± 0.37)			
Hand	9.69 ± 3.11	10.69 ± 2.75	8.69 ± 2.75	10.81 ± 2.97	9.75 ± 2.98	10.75 ± 2.84	3.57	0.019*	0.139
		(10.41 ± 0.3)		(11.42 ± 0.3)		(10.42 ± 0.3)			
								0.493^{A}	
								0.012^{B}*	
								0.013^{C}*	
Total	45.38 ± 8.78	50.25 ± 7.12	46.81 ± 7.71	51.88 ± 7.09	45.31 ± 7.29	51.44 ± 7.68	0.568	0.286	0.025
		(50.63±0.83)		(51.07±0.83)		(51.86±0.83)			
MAL									
AOU	0.93 ± 0.63	1.75 ± 0.87	0.91 ± 0.72	1.92 ± 0.90	1.03 ± 0.90	1.50 ± 1.12	3.71	0.016*	0.144
		(1.78 ± 0.14)		(1.97 ± 0.14)		(1.42 ± 0.14)			
								0.044^{A}*	
								0.18^{B}	
								0.005^{C}*	

QOM	0.98 ± 0.75	1.96 ± 0.92 (2.03 ± 0.18)	1.08 ± 0.83	2.05 ± 0.83 (2.04 ± 0.18)	1.15 ± 1.11	1.64 ± 1.23 (1.57 ± 0.18)	2.360	0.053	0.097

Note. Values are mean ± standard deviation (SD); values in bracket are means adjusted for covariate in the ANCOVA model; dCITRes, Distributed constraint induced therapy combined with trunk restraint; dCIT, Distributed constraint induced therapy; CT, controlled treatment; FMA, Fugl-Meyer assessment; MAL, Motor Activity Log; AOU, amount of use; QOM, quality of movement. **P* <.05. The superscript for comparisons between groups: A, distributed constraint induced therapy combined with trunk restraint group versus controlled treatment group; B, distributed constraint induced therapy combined with trunk restraint group versus distributed constraint induced therapy group; C, distributed constraint induced therapy group versus controlled treatment group.

Figure 1. Flow diagram of the randomization procedure

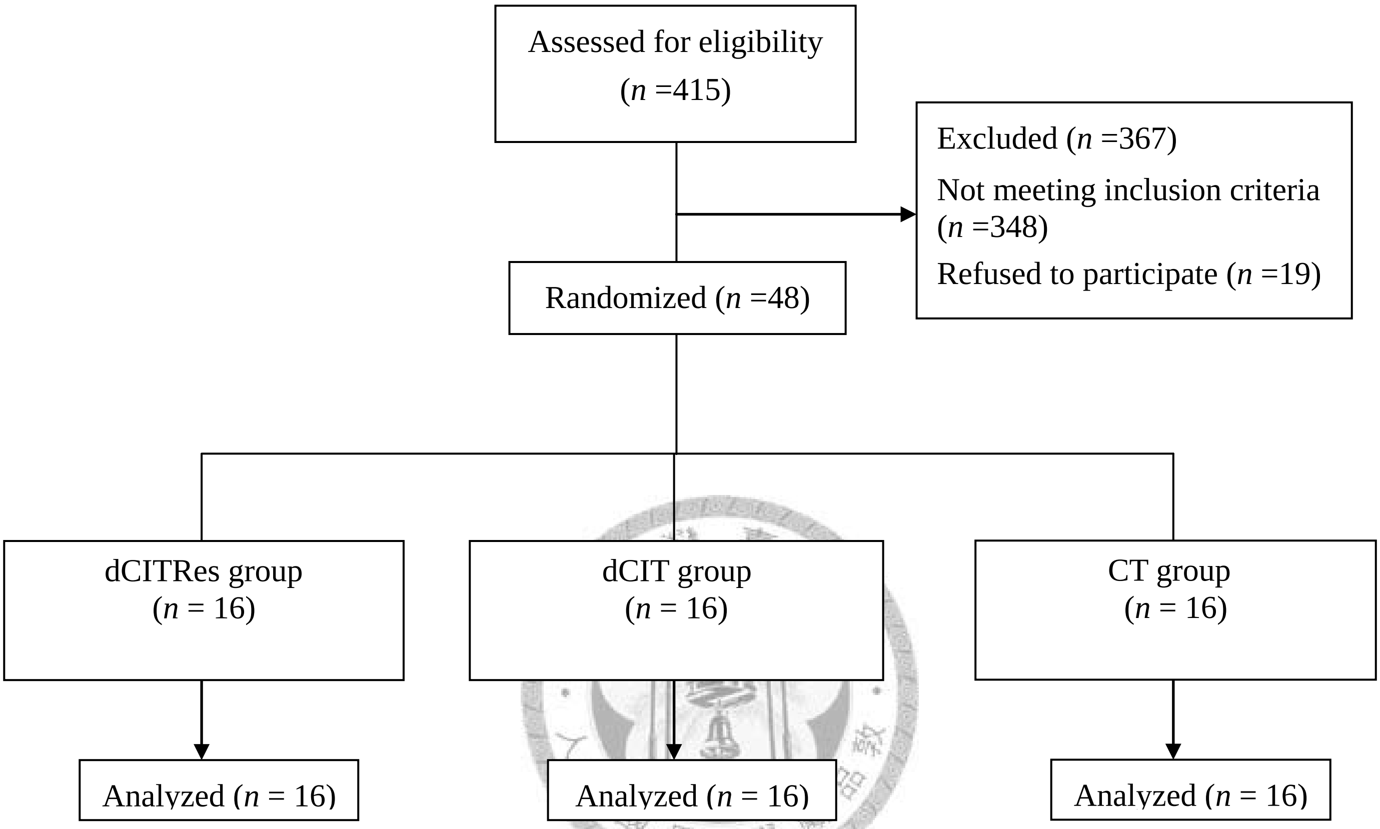


Figure 2. The experimental setup for the task with trunk restraint

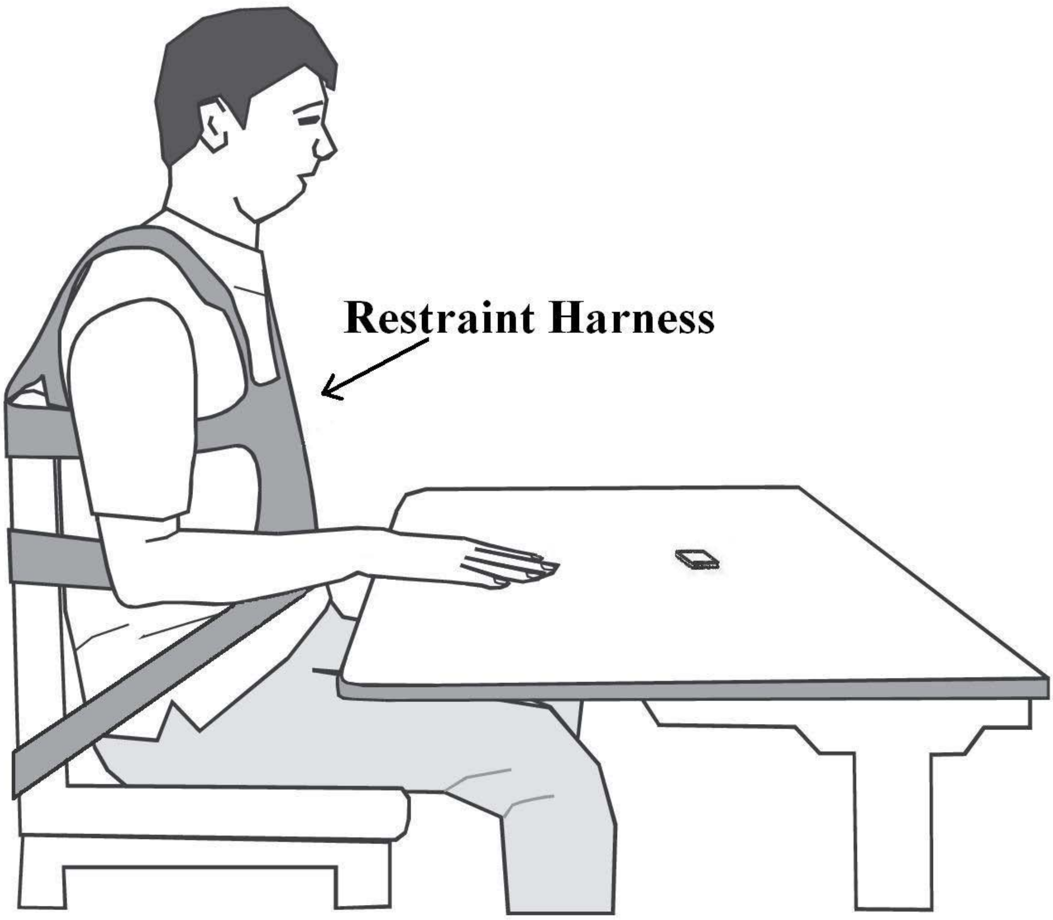
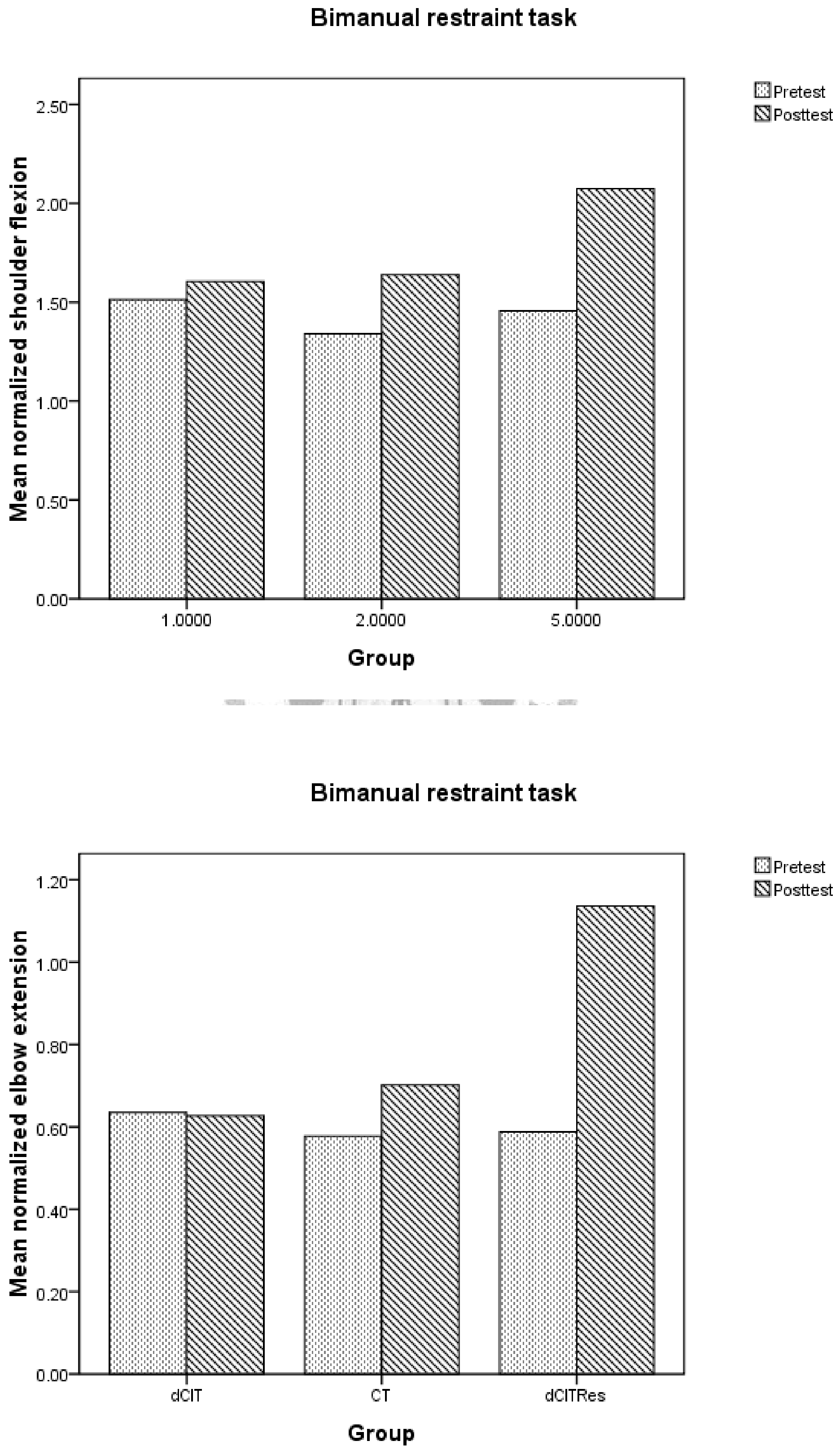


Figure 3. Kinematic variables for the bimanual restraint task during pre and posttest



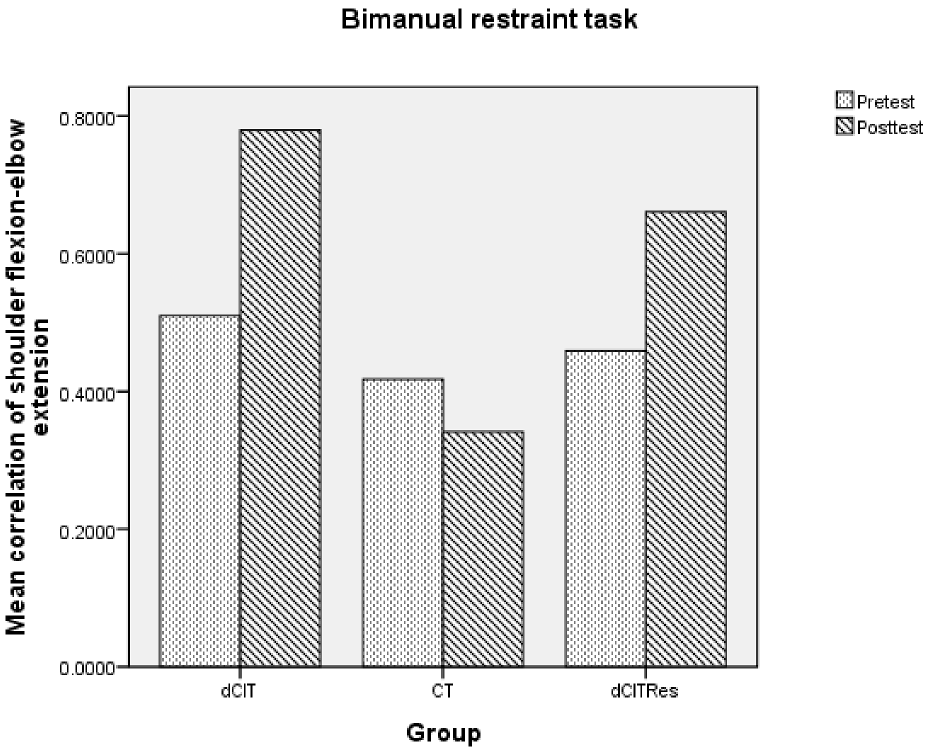
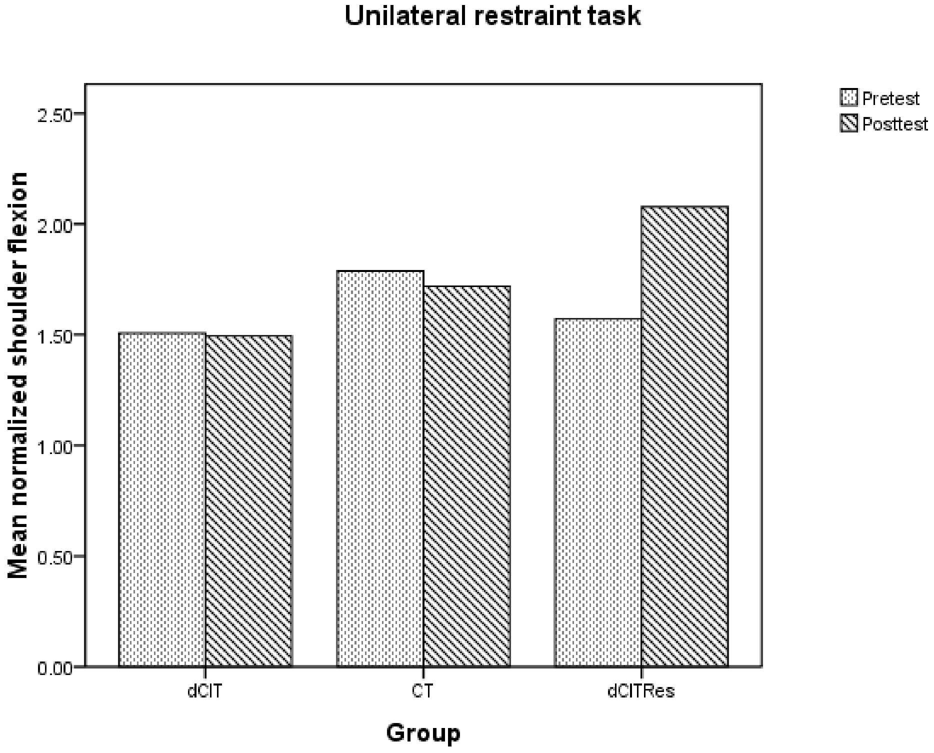
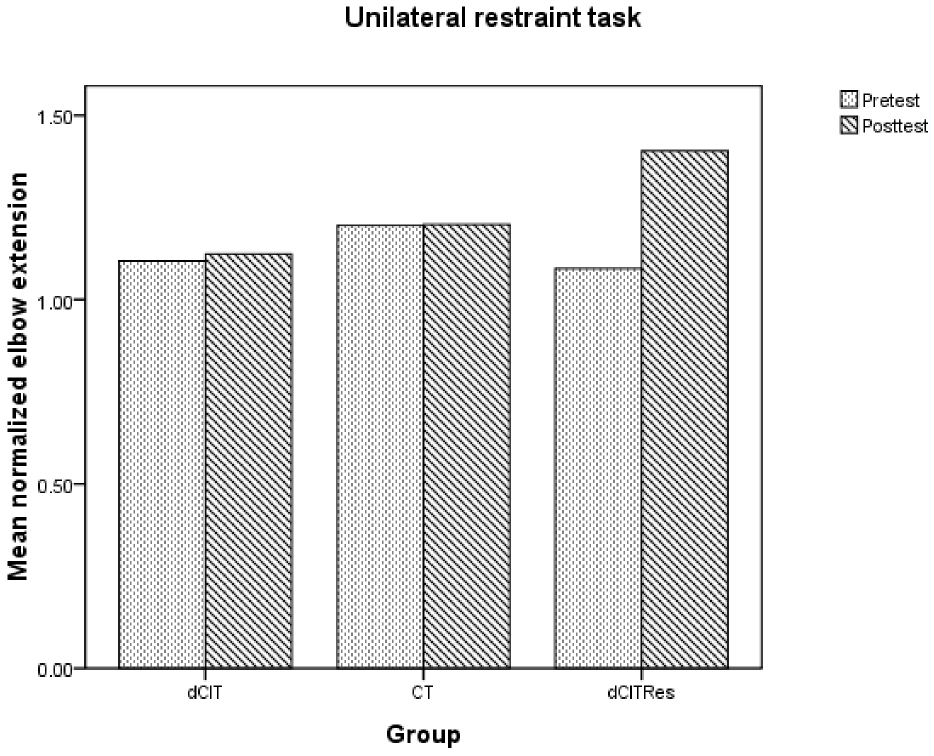
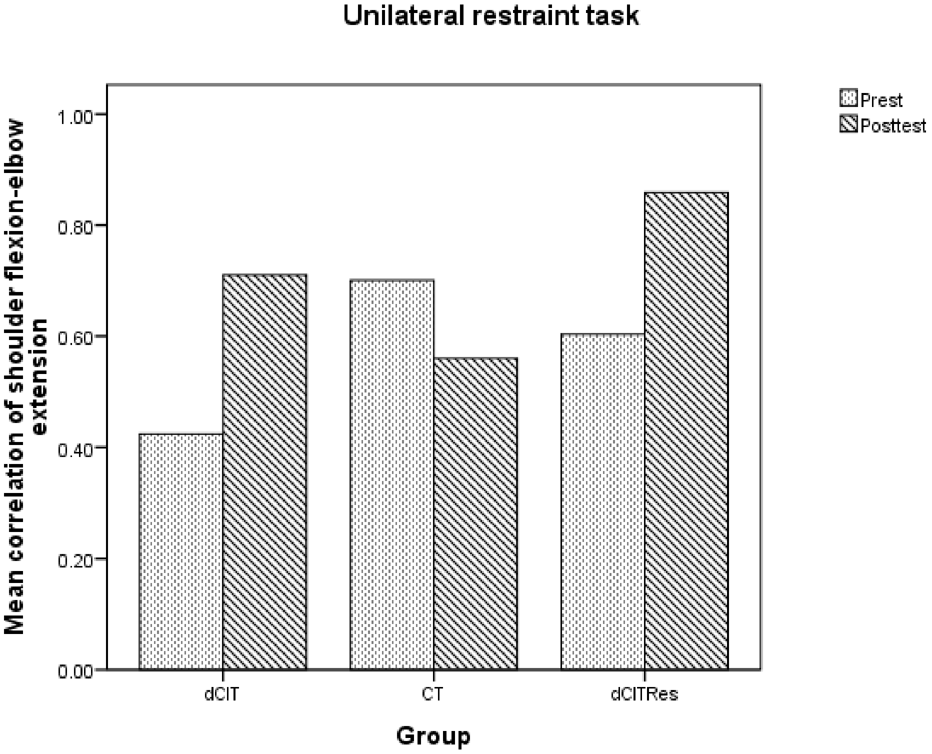

Bimanual restraint task
Mean correlation of shoulder flexion-elbow extension
0.8000
0.6000
0.4000
0.2000
0.0000
dCIT
CT
dCITRes
Group
▨ Pretest
▧ Posttest

Figure 4. Kinematic variables for the unilateral restraint task during pre and posttest






Unilateral restraint task
Mean correlation of shoulder flexion-elbow extension
1.00
0.80
0.60
0.40
0.20
0.00
dCIT
CT
dCITRes
Group
Prest
Posttest

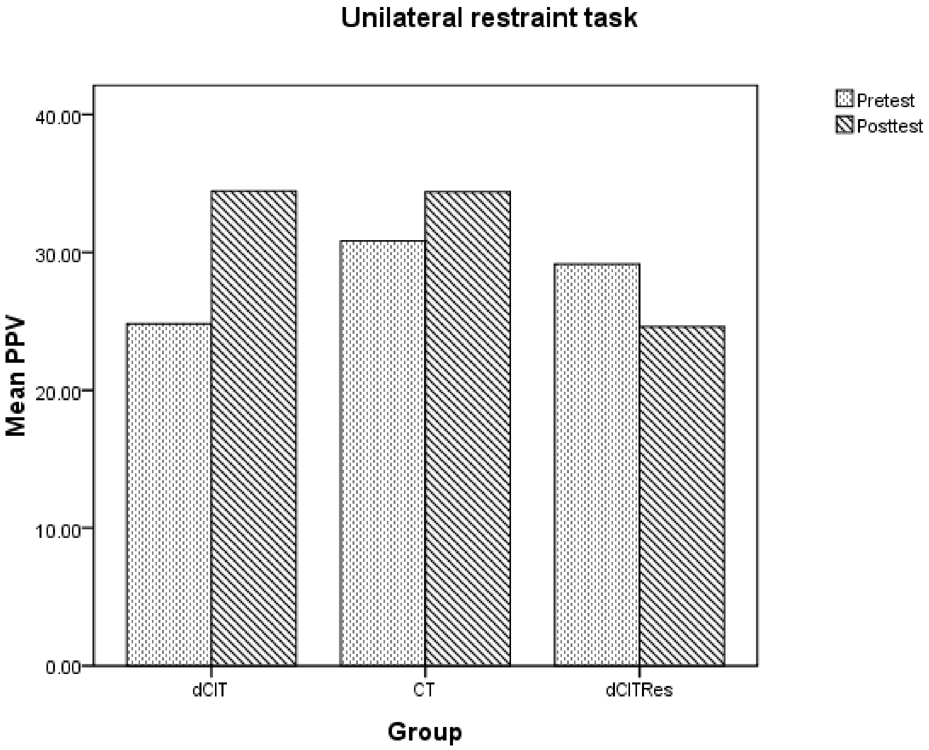
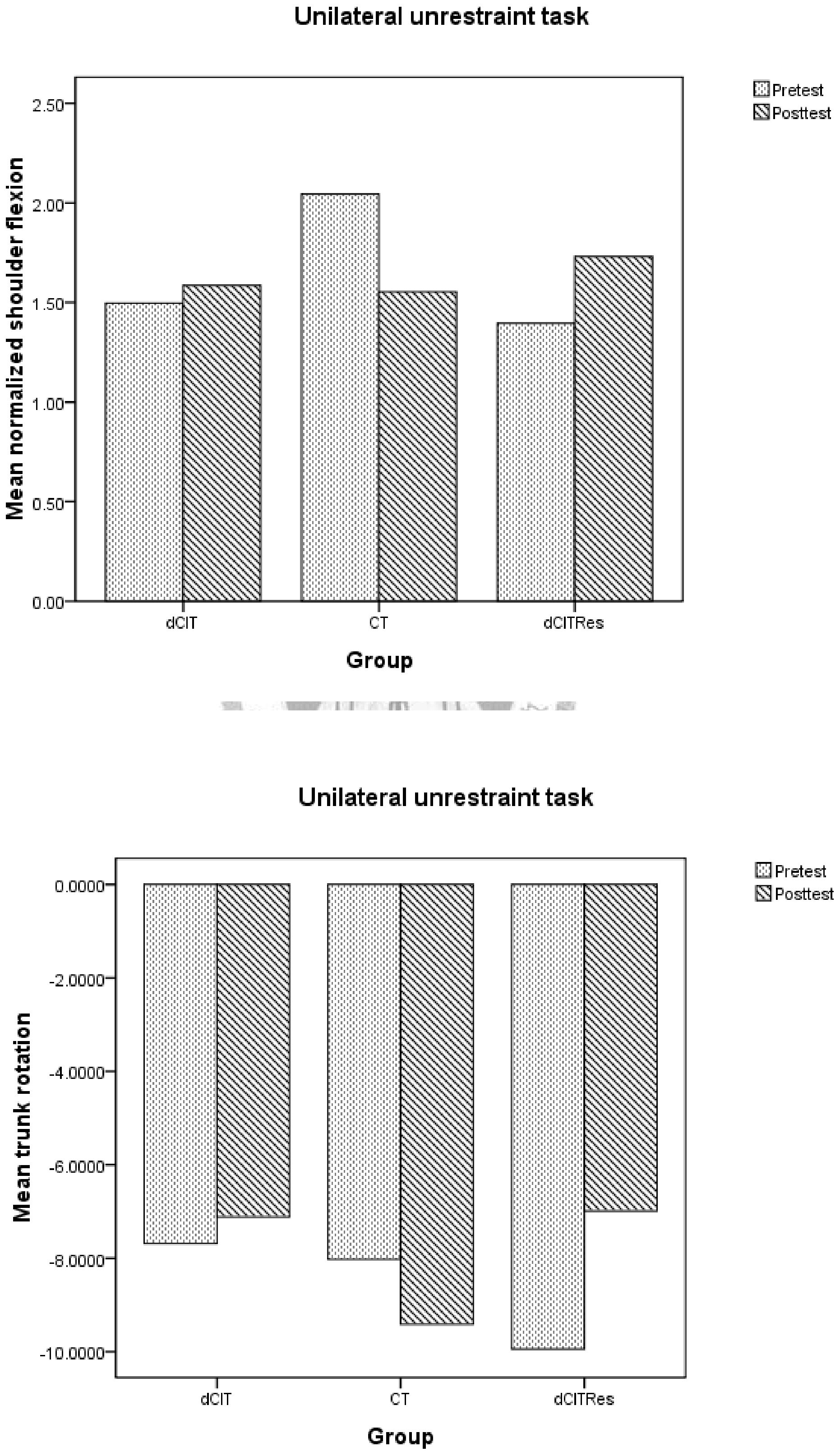
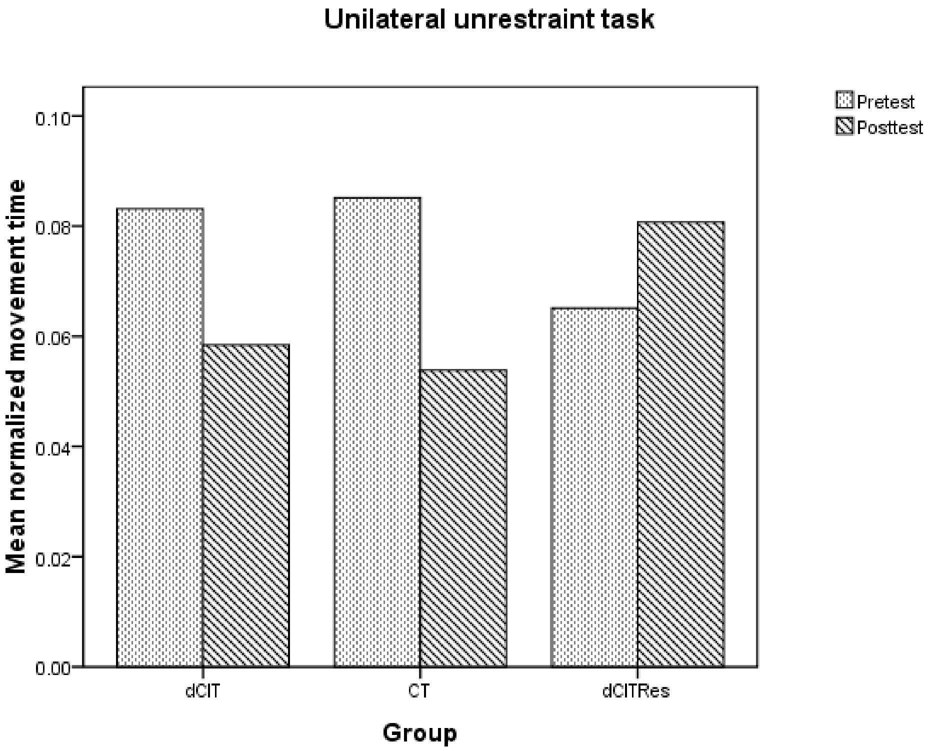

Unilateral restraint task
Mean PPV
40.00
30.00
20.00
10.00
0.00
dCIT
CT
dCITRes
Group
Pretest
Posttest

Figure 5. Kinematic variables for the unilateral unrestraint task during pre and posttest




Unilateral unrestraint task
Pretest
Posttest
Mean normalized movement time
0.10
0.08
0.06
0.04
0.02
0.00
dCIT
CT
dCITRes
Group