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ORIGINAL REPORT

EFFECT OF CROSSED-EDUCATION USING A TILT TABLE TASK-ORIENTED APPROACH IN SUBJECTS WITH POST-STROKE HEMIPLEGIA: A RANDOMIZED CONTROLLED TRIAL

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Objective: **To determine the effect of crossed-education, using task-related training on a tilt table, on upper extremity function and grip strength in subjects with post-stroke hemiplegia.**
Design: **Double-blind, randomized controlled, pilot study.**
Patients: **A total of 45 patients between 6 and 12 months post-stroke.**
Methods: **Subjects were randomly allocated to the control group, or experimental group I or II. All subjects received conventional upper limb training for 30 min, 3 times a week for 6 weeks, and training on 3 different tilt table applications for 20 min a day. The outcome was evaluated using the Fugl-Meyer scale, Wolf Motor Function Test, and measurements of grip strength using a hydraulic hand dynamometer, prior to and 6 weeks post-intervention.**
Results: **There was a significantly greater increase, post-test, in the Fugl-Meyer scale ($p=0.003$), maximal grip strength of the affected hand ($p=0.04$), and grip strength, compared with the less-affected hand ($p=0.03$), in subjects who underwent supplementary task-oriented training on a tilt table compared with those in the control group. There was also a significantly greater increase in Wolf Motor Function score ($p=0.001$), post-test, in subjects who underwent task-oriented training on a tilt table compared with those in the 2 experimental groups.**
Conclusion: **Compared with tilt table or conventional training alone, crossed-education using task-oriented training on a tilt table may result in improvements in arm function and maximal grip strength in persons with chronic hemiplegia post-stroke.**

Key words: crossed-education; hemiplegia; task-oriented training; tilt table; upper extremity.

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LAY ABSTRACT

Most patients who survive chronic stroke experience persistent impairment of upper limb movement. The ability of such patients to exercise the affected upper limb independently may be restricted by postural instability due to reduced lower limb functioning. A tilt table, which is commonly used in performing upper limb tasks in the clinical setting, was modified for safe and independent use in upper limb rehabilitation. Training on the modified tilt table was found to improve upper limb functioning and maximal grip strength following stroke. This novel therapeutic approach may be a potential neuro-rehabilitation strategy for stroke patients with various severities of upper limb impairment.

In individuals with post-stroke hemiplegia, upper extremity (UE) function depends on several factors, including the severity of paresis, the degree of spasticity, and the extent of motor and sensory loss (1). The majority of patients who survive a chronic stroke experience persistent impairment of UE movement (2). Post-stroke chronic UE paresis is also a leading cause of serious long-term disability related to hand function (1, 2). In particular, following a stroke, individuals also have a complex pattern of UE motor impairments, resulting in the loss of functional abilities, such as grip and grasping (2). Cirstea & Levin (3) suggested that loss of motor function in UE post-stroke may contribute to pain, joint contracture, and discomfort, which may lead to limb disuse and impede long-term functional recovery. Furthermore, reduced UE function impacts the ability to perform activities of daily living (4), reducing an individual's independence, and increasing the burden for caregivers. Therefore, the development and refinement of post-stroke rehabilitation strategies have the potential to improve an individual's function, and to decrease the burden on caregivers and the healthcare system.

Task-oriented training in stroke rehabilitation

A previous study has demonstrated the trainability of patients following stroke, and documented the beneficial strength-building and functional effects of various types of rehabilitation (5). A range of rehabilitation approaches has been used to improve skill reacquisition in the impaired arm (6). One of these approaches, task-oriented training, the practice of goal-directed functional movements in a natural environment, has recently become a common rehabilitation approach to address these goals. Task-oriented training involves

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variable practice to help the individual develop optimal control strategies to solve motor problems (7). For UE function, a case study of patients with hemiparesis, using a variant of task-oriented training, found improvement in clinical outcome measures. Furthermore, previous study (8), involving serial positron emission tomography, found that task-oriented training induces brain plasticity in patients post-stroke. Thus, task-oriented training is expected to promote the recovery of reaching in subjects with hemiparesis.

Definition and clinical relevance of crossed-education

"Crossed-education" or the "crossed-training effect" is an inter-limb phenomenon that was first reported by Scripture et al., in 1894 (9). It describes the increase in voluntary force-generating capacity of the opposite untrained limb, which occurs as a result of unilateral resistance training (9). Since then, crossed-education has been examined extensively in the literature (9–11), and has potential clinical relevance in exercise rehabilitation for patients who have conditions that prevent them from exercising 1 limb. These conditions may include acute injuries of the extremities, post-surgical limb immobilization, and certain neurological disorders with predominantly unilateral muscle weakness (12). If exercising the healthy limb can strengthen the injured or diseased limb, this could potentially minimize complications caused by disuse, and maximize the effectiveness of rehabilitation after the injury has healed (12).

Tilt table in stroke rehabilitation

In the clinical setting, the majority of therapists use manual therapy, such as neuro-developmental techniques or a supplementary tilt table, to increase the mobility of UEs and to perform supported-weight load training in patients (13). The tilt table has become a useful device in the mobilization of patients with traumatic brain injury and spinal cord injury, as well as in patients with acute to chronic stroke (14), when used under the supervision of physical therapists. In particular, the position of stroke patients can be changed continuously from horizontal to vertical using the tilt table during the early and late stages of rehabilitation. As a result, during training, patients can independently adapt to the state of walking prior to actually attempting to walk, thus helping reduce muscle atrophy and weakness (13).

The need for the present study

No effective standardized method for using the tilt table as a supplementary treatment in the rehabilitation of patients post-stroke has been published. The tilt table has thoracic, pelvic, and knee safety belts to hold the patient's body while they are standing or leaning against it, and which prevent them from tipping forward. It has been adapted for use by physical therapists, with its angle being gradually increased (15, 16). In general, in the clinical setting, the patient is strapped with knee belts on both the affected and less-affected lower extremities (LEs), which do not allow any movement or exercise of the UEs. This leads to delay in the proprioceptive input and thus in muscular activity of the affected LEs and UEs, and in achievement of sufficient locomotion or reaching and grasping ability to perform various activities of daily living (17). Furthermore, there have been no previous studies into the effect of crossed-education using task-oriented training on a tilt table in patients post-stroke, including longitudinal quantitative data regarding changes in UE function and grip strength associated with motor recovery of the UE. The lack of a quantitative standardized measurement for UE function and grip strength remains a critical issue in assessing the effects of task-related training on a tilt table in patients post-stroke.

Objectives

Based on the above background research, the aim of this study was: to evaluate the effect of crossed-education using task-oriented training on a tilt table, while applying a knee belt in different ways, on UE function and maximal grip strength in the rehabilitation of patients post-stroke. The study addressed the hypothesis that task-oriented training on a tilt table would improve UE function and maximal grip strength following stroke. It also predicted that task-oriented training on the tilt table, as a supplement to convential rehabilitation would be more effective than supplementary use of the tilt table without task-oriented training.

METHODS

Participants

A total of 45 subjects (21 women and 24 men) with post-stroke hemiplegia, admitted to a stroke rehabilitation institute, were enrolled in the present study. All subjects provided written informed consent prior to enrolment. The study was approved by the Human Research Sciences Local Ethics Committee, and registered with the University Clinical Trials Registry (K1605431). The sample size estimate was based on data collected from previous studies (18, 19). In the case of a 20% drop-out rate, a priori power analysis determined that a sample size of 15 subjects post-stroke in each group was required to obtain a statistical power of 0.80 using the general power analysis program 3.1 (Kiel University, Germany) (20). This was based on one-way analysis of variance (ANOVA) measurements of the comparison among 3 groups with a predetermined coefficient of reliability of 0.8. Stroke diagnosis and location of lesions were based on computed tomography or magnetic resonance imaging, as well as neurological functions. Inclusion criteria were: (*i*) discharge from rehabilitation services following unilateral stroke 6–12 months previously; (*ii*) ischaemic or haemorrhagic post-stroke hemiplegia; (*iii*) a score of at least 26 on the Korean version of the Mini-Mental Status Examination (MMSE-K); (*iv*) no excessive spasticity in the more affected UE; (*v*) able to reach Brunnstrom stage III or IV in the proximal and distal parts of the UEs (18); (*vi*) independently able to perform specific activities of daily living, such as assistance needed for movement from wheelchair to bed, and self-maintained sitting posture; and (*vii*) no excessive pain in the more affected UE (18). The degree of spasticity and pain were measured using the Modified Ashworth Spasticity (MAS) scale and a 10-point visual analogue scale (VAS), respectively. Individuals scoring less than or equal to 3 on the MAS scale, and less than or equal to 4 on the VAS were included in the study (18). Subjects were excluded if they were independently able to perform unaided standing, unassisted walking in the ward, and they had previous musculoskeletal abnormalities, confusion, neurological disorders, or unilateral neglect. Unilateral neglect was tested using the star cancellation test of visuospatial neglect; patients scoring less than 47 were excluded from the study (19). Subjects were randomly allocated to 3 groups: control group (CG), experimental group I (EG_1), or experimental group II (EG_2). Block randomization was preferred to ensure equal numbers of subjects among the 3 groups and a block size of 6 was chosen. Sequentially numbered, opaque, sealed envelopes were used for allocation concealment. Each block was placed in 1 of the envelopes and the envelopes were opened according to a computer-generated random-number table. Consequently, the subjects and therapists were not aware of their grouping. The baseline characteristics of all subjects in each group are shown in Table I. The data indicate that the groups had similar demographic characteristics.

Outcome measures

Changes in the functional performance and motor control of UEs were assessed using clinical evaluation and the maximal grip strength test, which were administered prior to, and following, the 6-week intervention period. One physical and one occupational therapist, blinded to the group allocation, provided the assessments. Prior to the administration of clinical measures, the blinded evaluators underwent an 10-h training session on the administration of the Fugl-Meyer scale (FMS) test of UEs (21) and the modified Wolf Motor Function Test (WMFT) (22). The rater competence was assessed by the primary investigator, who has 10 years' experience in the use of such measures. The evaluators were trained to conduct the maximal grip strength measurements in accordance with the standardized procedures described below. Subjects were advised not to indicate their treatment assignment to the evaluator.

Clinical evaluations

Post-stroke UE motor impairment was assessed by a physical therapist using the UE subsection of the FMS assessment test (21, 23). The evaluator rated the condition of 30 voluntary UE movement patterns on a 3-point ordinal scale, and tested the excitability of 3 tendon-tap reflexes on a 2-point ordinal scale. Traditionally, the assessment is scored by summing the item ratings and reporting the aggregate score out of 66 points, with higher scores representing a greater UE motor ability (23).

UE motor function was also measured by an occupational therapist using the WMFT. Subjects were timed as they completed 15 activities that involved progressively more difficult UE movements and interactions with objects, such as lifting a soft-drink can, stacking chequers, and folding a towel. The mean time to perform the 15 items was reported, and the evaluator rated the condition of these items on a 6-point (range 0–5) functional ability scale (24). In general, the assessment is scored by summing the item ratings and reporting the aggregate score out of 75 points, with higher scores representing greater UE motor ability.

Maximal grip strength measurement

The maximal grip strength was measured using a calibrated Jamar hydraulic hand dynamometer (Sammons & Preston Rolyan, Bolingbrook, IL, USA). This tool has been shown to be valid and reliable with a high inter-rater reliability (25). The position of the dynamometer was adjusted to the subject's hand size. Subjects performed the test sitting on a bed or chair in the posture found to produce the most accurate results (26); shoulders adducted and neutrally rotated, the elbow flexed at 90°, and the wrist neutrally positioned if possible. Each subject was given a demonstration and then asked to maximally grip the handle of the dynamometer for 3 s. To minimize variance in the psychomotor motivation (25), a standardized encouragement

Table I. Subject characteristics for each group (*n* = 45)

Characteristics	Control group (*n* = 15)	Experimental group I (*n* = 15)	Experimental group II (*n* = 15)
Age, years, mean (SD)	60.41 (5.84)	59.47 (6.24)	58.44 (9.01)
Weight, kg, mean (SD)	61.71 (4.74)	66.57 (5.79)	63.91 (4.67)
Height, cm, mean (SD)	165.09 (4.87)	162.03 (5.80)	164.74 (5.75)
Post-stroke duration, months, mean (SD)	6.34 (3.44)	7.14 (4.94)	8.46 (4.77)
Body mass index, kg/m^2, mean (SD)	22.37 (2.94)	20.07 (1.57)	21.97 (1.55)
Mini-Mental State Examination, mean (SD)	26.74 (2.54)	25.97 (3.42)	26.67 (4.79)
MAS (score), mean (SD)	1.97 (0.07)	2.01 (0.97)	2.12 (0.54)
VAS (score), mean (SD)	2.09 (0.31)	2.74 (1.07)	2.30 (0.13)
Star Cancellation Test (maximum = 54), mean (SD)	50.87 (1.04)	51.24 (0.79)	51.97 (2.75)
Gender (male/female), *n*	9/6	10/5	5/10
Ischaemic/haemorrhagic, *n*	7/8	8/7	7/8
Plegic side (right/left) *n*	9/6	5/10	7/8
Brunnstrom stage of upper extremity, *n*			
Stage 3	9	7	8
Stage 4	6	8	7

SD: standard deviation; MAS: Modified Ashworth Spasticity scale; VAS: visual analogue scale; SD: standard deviation.

was given to each subject; “Squeeze as hard as you can, harder, harder, relax”, saying “relax” at 3 s. The mean of 3 trials of maximum grip strength were recorded for the affected and less-affected hand, with no less than 10 s and no more than 30 s rest between tests. To avoid confounding the values based on age, the maximal grip strength of the affected hand was compared with that of the unaffected hand (27).

Intervention procedures

The test procedures are shown in Fig. 1. Over a 6-week period, all subjects received conventional upper limb training, including techniques for activities of daily living, UE strength, therapist-guided techniques for facilitating normal UE movement patterns, and range of motion and traditional positioning. They received the above conventional upper limb training for 30 min, 3 times a week. The subjects in each group additionally received supplementary training on a tilt table (Midland Manufacturing Co., Inc., Columbia, SC, USA) for 20 min a day while positioned in such a way that they felt comfortable at a tilted angle. Each group received training on the following 3 different tilt table applications: CG – subjects were strapped with thoracic, pelvic, and both-knee safety belts; EG_1 – while subjects were strapped with thoracic, pelvic, and only affected-side knee safety belts, they performed 1-leg standing training with the less-affected LE for 10 s, followed by a 5-s rest period; EG_2 – while subjects were strapped with thoracic, pelvic, and only affected-side knee safety belts, they performed progressive task-oriented training, such as target-matched exercises and throwing a ball, using the less-affected UE, during 1-leg standing with the less-affected LE (Fig. 2). The outcomes were measured prior to, and following, the 6-week intervention period.

At first, subjects in EG_2 stood and leaned against the tilt table with their trunk restrained to prevent compensatory trunk movement, such as lateral trunk flexion and rotation forward affected side. Corrective feedback was given if compensatory movements were observed. Other tasks were also used to minimize compensatory movements. The subjects started with an easy task, such as close target-matched reaching and light-load throwing training. Upon correct completion of the easy task, the subjects were allowed to perform increasingly difficult tasks, such as far target-matched reaching and heavy-load throwing training. The therapist also determined the task level of each subject on the basis of the progressive load principle (28). For the target-matched reaching and ball-throwing training, familiar objects, such as plastic balls, were used that varied in size, shape, and weight (26–253 g). The subjects were only allowed to reach and throw in the sagittal plane of the anterior-posterior direction. Training frequencies, intensity, such as repetition of sets and weights, and timing were determined the task performance of each subject according on the basis of the principle of progressive load (28), and training involved only the less-affected UE. The instructions were to move at a preferred speed and to increase that speed as training progressed. Subjects in EG_2 performed a total of 5 sets, with 10 repetitions in each set. Following completion of each set, a 1-min resting time was allowed. The angle of the tilt table, measured between the surface of the table and the horizontal plane, was varied from 0° to 90°. During the 20-min intervention, all subjects were placed in the supine position on the tilt table, and were allowed to increase their maximum tilt angle gradually, and to reduce their tilt angle during a session if they felt light-headed. If the subjects experienced dizziness or nausea during the experimental procedures, the experiment was stopped immediately, and the subjects were allowed to rest in the supine position. Furthermore, a therapeutic foam roller (length 60 cm, width 15 cm) was used to prevent knee hyper-extension.

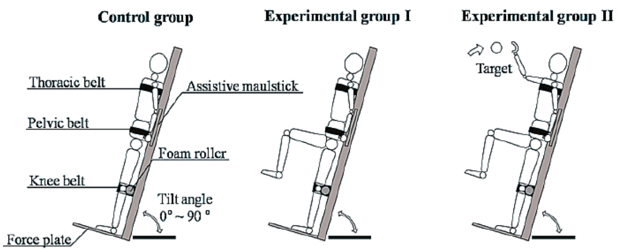

Fig. 2. Tilt table application method in the 3 study groups.

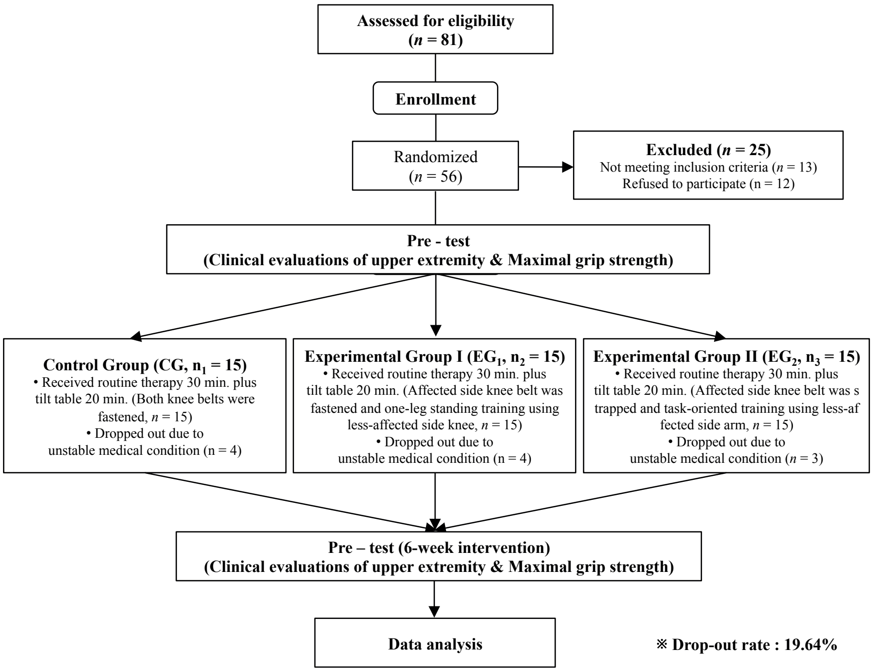

Fig. 1. Study flow chart.

Data processing and statistical analysis

Statistical analysis of the data was performed using the SPSS software version 12.0 (SPSS Inc., Chicago, IL, USA). The values in each group are expressed as the mean and standard deviation, number (*n*), and percentage (%). Since the Kolmogorov-Smirnov test did not reject the hypothesis of a normal distribution for any variables in the study, parametric methods were used. The χ^2 test (gender, type of stroke, side of hemiplegia, and Brunnstrom stage of upper extremity) and 1-way ANOVA (age, weight, height, duration since stroke, body mass index (BMI), MMSE-K, and star cancellation test score) were used to compare demographic characteristics of subjects among the 3 groups. Comparisons of the pre- and post-test clinical scores of UEs and maximal grip strength among the groups were investigated using repeated-measures 1-way ANOVA for continuous data, followed by Bonferroni's *post-hoc* test to identify the differences between 2 groups at each intervention time. The paired *t*-test was used to compare the same parameters prior to, and following, intervention within each group. The significance level was set at $p<0.05$.

RESULTS

Subjects' characteristics

From an initial 81 subjects with stroke who were invited to join the study, 25 declined to participate or did not meet the inclusion criteria, and 11 withdrew due to an unstable medical condition. Thus, a final total of 45 subjects were included, and the drop-out rate was 19.64% .

Comparison of clinical scores among groups

The overall changes in clinical scores are listed in Table II. Significant pre- to post-test differences were found in the FMS UE test score in each group ($p<0.05$). In particular, *post-hoc* testing revealed that the post-test FMS scores of subjects in EG_1 and EG_2 ($p<0.01$) were significantly different from those of subjects in CG. Significant pre- to post-test differences in WMFT score were found only in EG_2 ($p<0.01$). *Post-hoc* testing revealed that the post-test WMFT scores of subjects in EG_2 ($p<0.01$) were significantly different from those of subjects in CG and EG_1.

Comparison of maximal grip strength among groups

Table II also reflects the overall changes in maximal grip strength of the affected hand and the grip strength compared with the less-affected hand. The improvement was significantly greater in EG_2. In particular, *post-hoc* testing revealed that both the maximal grip strength of the affected hand and the grip strength compared with the less-affected hand, of subjects in EG_2 ($p<0.01$), were significantly different from those in CG and EG_1. The post-test strength values of subjects in EG_1 ($p<0.05$) were significantly different from those in CG.

DISCUSSION

Study overview

Stroke causes UE motor deficits that compromise the performance of activities of daily living. Of all people with stroke, 30–66% continue to experience UE motor dysfunction for more than 6 months (1). Subjects were enrolled in the present study more than 6 months post-stroke in order to measure the recovery of UE motor dysfunction. This is the first study of the clinical benefits of crossed-education, using supplementary, progressive, task-oriented training on a tilt table, on UE function and maximal grip strength of patients with post-stroke hemiplegia. This is also the first study to compare specific protocols for crossed-education using a tilt table in stroke rehabilitation, in addition to comparing task-oriented protocols with subjects who do not perform task-oriented training

Table II. Comparison of clinical scores of upper extremities and maximal grip strength among the 3 groups ($n=45$)

Characteristic	Control group Mean (SD) ($n=15$)	Experimental group I Mean (SD) ($n=15$)	Experimental group II Mean (SD) ($n=15$)	F (p-value^{b})
Fugl-Meyer upper extremity test (score)				
Pre-test	31.57 (13.74)	30.17 (14.64)	30.14 (11.09)	
Post-test	34.79 (12.20)	43.74 (13.50)^{c}	45.01 (12.97)^{c}	11.02 (0.02)*
t (p-value^{a})	−3.35 (0.04)*	−9.23 (0.003)**	−10.54 (0.002)**	
Wolf Motor Function Test (score)				
Pre-test	40.17 (16.23)	41.09 (15.43)	39.17 (16.91)	
Post-test	41.03 (15.87)	43.97 (14.11)	53.74 (17.05)^{c,d}	14.32 (0.001)**
t (p-value)	−0.91 (0.45)	−0.75 (0.67)	−10.10 (0.003)**	
Maximal grip strength (MGS, kg)				
MGS of the affected side (kg)				
Pre-test	14.40 (6.54)	15.00 (7.07)	14.57 (6.11)	
Post-test	17.69 (9.41)	21.34 (10.22)^{c}	27.99 (9.17)^{c,d}	40.51 (0.000)**
t (p-value)	−0.91 (0.07)	−4.70 (0.04)*	−13.14 (0.001)**	
Grip strength compared with the less-affected hand (%)				
Pre-test	51.29 (20.90)	50.04 (19.79)	51.55 (20.74)	
Post-test	59.07 (24.74	74.07 (20.91)^{c}	83.04 (25.37)^{c,d}	42.76 (0.000)**
t (p-value)	−2.96 (0.06)	−6.59 (0.03)*	−19.54 (0.001)**	

*$p<0.05$, **$p<0.01$.

Grip strength compared with the less-affected side: (mean maximal grip strength of the affected hand/mean maximal grip strength of the less-affected hand) × 100. ^{a}Intra-group comparison. bInter-group comparison. ^{c}Significantly different compared with the control group. ^{d}Significantly different compared with the experimental group I.

of UE. Rehabilitation with supplementary effective standardized use of a tilt table strongly influenced UE motor recovery in patients post-stroke. This application protocol, with the possibility of progressive inclination towards vertical alignment, prepares patients for a smooth transition to the upright position, by gradually increasing the load on the affected leg. The results of this study suggest that the use of supplementary, progressive, task-oriented, UE training on a tilt table has positive effects on UE performance in individuals with post-stroke hemiplegia. Despite the advantages of training using the application protocol, in conjunction with supplementary use of a tilt table, it is worth emphasizing that this rehabilitation programme serves only as a supplement to daily standard therapeutic treatment. An important aspect of supplementary, progressive, task-oriented, training on a tilt table is that it is accompanied by active participation of the patient.

Clinical evaluation and measurement of maximal grip strength

The present study used clinical evaluation to investigate changes in motor control impairment and functional motor performance of UEs, using the UE FMS test and WMFT, respectively, following progressive task-oriented training on the tilt table. By assessing these clinical evaluations, it is possible to examine whether functional improvement is accompanied by a change in motor performance of the UE (29). The impairment and disability of the UEs were generally assessed using ordinal scales, such as the FMS test and WMFT (30). Moreover, the majority of studies have reported composite scores of standardized tests, such as the FMS test or WMFT, rather than determining how the motor control or coordination of arm movements have changed (29, 30).

Maximal grip strength is a good indicator of overall UE strength, and even of the whole neuromuscular system function, and is associated with the ability to perform activities of daily living (31). There are numerous situations in which maximal grip strength reference values are needed. For instance, the functional measurement and follow-up of individuals may be considered within the time frame of disease and therapy, medicolegal issues, or injuries and rehabilitation. Thus, maximal grip strength is implicitly linked to functional autonomy, and hence, to quality of life. This relationship has already been shown in stroke patients, and grip strength is a suitable phenotype for identifying genetic variants of importance to mid- and late-life physical functioning (32). In a study by de Souza et al. (33), grip strength was found to correlate positively with fat-free mass and height ($r \geq 0.75$). Data on BMI and height prior to intervention can be used to minimize the confounding factor of body fat and to maintain homogeneity of muscle quality. In addition, to avoid confounding the values based on age, the maximal grip strength of the affected hand was compared with that of the unaffected hand (27).

Crossed motor function and grip strength gains in the affected upper extremity

This study revealed a greater increase in maximal grip strength of the affected hand compared with the less-affected hand, and an improvement in UE FMS test and WMFT scores in subjects who underwent supplementary, progressive, task-oriented, training on a tilt table compared with those in the other groups. In particular, improvements were measured in the torque generated by the maximal grip strength of the affected hand and the grip strength compared with the less-affected hand, which have previously been correlated with UE functional performance (29). Furthermore, significant gains in the voluntary UE strength of the untrained affected side following stroke can be achieved through task-oriented training of the less-affected side. It is possible that contralateral influences operate from the less-affected arm to the affected arm, and that the strength is enhanced by task-oriented training. Previous studies have demonstrated activation of the affected primary motor cortex during upper and lower limb movements of the less-affected side. Weiller et al. (34) found that, in control subjects, and for the less-affected hand of patients, the contra-lateral motor cortex and pre-motor areas were active while patients sequentially touched their thumbs to the different fingers of the same hand. Dragert & Zehr (35) also reported that unilateral dorsiflexor high-intensity resistance training on the less-affected side increases strength and motor output bilaterally following stroke. This finding is in accordance with results suggesting that short-term, task-oriented training of the less-affected side of the body, on the tilt table, causes “crossed” strength gains in the contralateral untrained limb (36, 37). In summary, unilateral task-oriented training may activate neural circuits that chronically modify the efficacy of motor pathways that project to the opposite untrained limb. This may result in increased capacity to drive the untrained muscles, and thus lead to improved functional capabilities. A number of spinal and cortical circuits are thought to exhibit the potential for this type of adaptation (12). This therefore demonstrates the clinical application of the crossed-education effect, where training the affected side is not initially possible. Moreover, it implies that the crossed-education effect may be clinically feasible as a promising approach to encourage a reduction in UE motor impairment and an increase in the maximal grip strength of patients with hemiplegic stroke.

Efficacy of the task-oriented approach on the tilt table

This study progressively applied various functional activities and task-oriented training on a tilt table using the less-affected UE. Subjects wore thoracic, pelvic, and affected-side knee safety straps. The efficacy of the task-oriented approach in repeatedly performing practice movement tasks that are relevant to the patients' actual lives has been accepted (38). The principles can also be used to organize supplementary, progressive, task-oriented, training using a tilt table, with increasing clinical benefits in practicing tasks. The clinical benefits of such training on a tilt table may be associated with the familiarity of the tasks. The results of the current study suggest that supplementary, progressive, task-oriented training on a tilt table may be a clinically feasible and promising approach for enhancing the functional performances of UE and grip strength in patients with post-stroke hemiplegia, considering its clinical benefits and ease of application.

Study limitations

The study has some limitations. First, a 6-week intervention period post-stroke may not be long enough for significant changes in mechanical properties to occur. Thus, the study does not show the long-term effect of supplementary, progressive, task-oriented, UE training on a tilt table. Secondly, the study did not measure biomechanical or kinematic parameters, such as relative joint moments, inter-joint coordination of UEs, or actual function, using tests of manual dexterity. Future studies would provide direct qualitative parameters during fully-supported trajectory tracking, measuring the biomechanical parameters and electromyography recordings from the UE muscles. Finally, the study did not analyse parameters that had a negative influence on gait pattern in stroke subjects through observed findings of lower extremity (LE) function. Nevertheless, a previous study (39), a single-blinded randomized controlled trial (RCT), published in 2015, found that crossed-education using task-oriented training on a tilt table resulted in an improved gait symmetry ratio and double support period of subjects with post-stroke hemiplegia in the chronic stage. However, further research, measuring these parameters in stroke patients in various conditions, is needed to provide direct quantitative information. Thus, a future RCT should be performed to confirm these findings, and to overcome above limitations.

It is important to establish the efficacy of treatment approaches that are appropriate for post-stroke patients who have UE impairments. The current results demonstrate, for the first time, that supplementary, progressive, UE task-oriented training on a tilt table increases UE function and maximal grip strength in patients with hemiplegic stroke. Therefore, this proposed therapeutic approach may be a novel neuro-rehabilitation strategy for patients with various severities of UE impairment.

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