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Original Article

Effects of computer-assisted wrist/hand training on the improvement of hand function in traumatic hand injuries

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Abstract: Objectives: To investigate the effects of computer-assisted wrist/hand intervention on the improvement of hand function for patients with traumatic hand injuries. Material and methods: A total of fifty-six participants with traumatic hand injuries involving bone or/and flexor tendon were randomly assigned to a computer-assisted therapy group (experimental group) and control group. Physical modalities and range of motion exercises were applied for all patients. In addition, patients in experimental group received computer-assisted wrist/hand strengthening training, while patients in control group received conventional strengthening exercises. Before and after 4-week intervention, all subjects were assessed by total active motion (TAM), grip and pinch strength, nine-hole pegboard test and upper extremity functional index (UEFI). Results: Fifty-one patients were enrolled in this study. No significant difference was found in demographics and other baseline outcome measures between groups. After 4-week training, significant improvements were found in all these measures in both groups. Moreover, patients in computer-assisted therapy group performed better in grip strength, lateral pinch strength, nine-hole pegboard test and UEFI scores, when compared to patients in conventional therapy group. During training, no severe complications were found in the experimental group. Conclusions: Computer-assisted wrist/hand intervention exhibited better results in improving hand strength and dexterity for hand injuries. It might be an alternative treatment for hand injuries in both clinical and home-based rehabilitation practice.

Keywords: Computer-assisted therapy, traumatic hand injuries, hand, wrist, rehabilitation

Introduction

Hand injuries are among the most common body injuries and account for 6.6%-28.6% of all injuries and 28% of injuries to the musculoskeletal system [1]. Hand injuries occur mainly during industrial activities and professionally active young workmen are most susceptible to the injuries [2]. Pain, edema, joint stiffness, joint deformity, muscle tightness and reduced hand strength due to hand injuries tend to result in persistent disabilities, and profoundly hamper the patients from returning to previous occupations, daily and leisure activities [3]. These injuries lead to major financial loss from time away from work (indirect cost) and medical expense (direct cost), and thus may put a significant economic burden on both patients and the society [4].

Traditional hand rehabilitation is based on the repetition of several simple movements without task-specific training or feedback, thus inevitably reducing patients' motivation and adherence to treatment. In fact, the one-to-one patient-therapist training pattern increases the cost of human resources. Therefore, researchers are making great effort to work out cost-effective therapeutic alternatives for hand rehabilitation. Recently, computer-assisted training, involving use of virtual reality [5, 6] and gaming devices [7], has been employed for hand rehabilitation of stroke patients and showed promising results.

A variety of devices, such as haptic gloves [8, 9] and robotic assisted devices [10], have been developed for computer-aided hand exercises for stroke patients. However, a few studies focused on patients receiving hand surgery [11]. Patients with traumatic hand injuries usually have difficulties in donning sensing gloves or exoskeletal robotic device [12]. Meanwhile, most devices exert force on hands, so patients with hand injuries may sustain secondary injuries caused by excessive force applied. Moreover, the equipment might be too expensive for some clinics or for personal use. Since most multiple-tissue hand injuries are of complex nature, it is necessary to develop a simple, safe and inexpensive device for the rehabilitation of hand injuries [13].

Computer games have been reported to provide interesting, motivating and challenging activities and to serve as an affordable and readily-available rehabilitation therapy [14]. Though evidence of the efficacy of commercially-available video games in rehabilitation remains lacking [15], it is an interesting idea to use off-the-shelf gaming devices for rehabilitation purpose [7]. Since commercially-available gaming devices are not designed for people with motor disabilities, they may have to be modified to suit clinical application [16].

Since wrist and hand are functionally integrated for serving their purposes [17]. In this study, we developed a video-games-based hand rehabilitation system, which was designed to train wrist-hand functions simultaneously. This interactive equipment was made from a conventional joystick. The original handle was modified into ellipsoid handle for easy gripping and equipped with force sensor resistors (FSRs) for sampling pinch force. Moreover, the device is inexpensive and easy to install. The objectives of this study were to assess the safety, feasibility of computer-assisted wrist/hand treatment program for the rehabilitation of hand injuries and to evaluate its effects on hand rehabilitation as compared with conventional treatment.

Materials and methods

Participants

Potential participants were recruited from inpatient rehabilitation center during June 2012-December 2014. The ethical approval was obtained from the hospital's research ethical committees. Before study, written informed consent was obtained.

The inclusion criteria was: (1) had experienced traumatic injuries to the hand or/and wrist, involving bone or/and flexor tendon; (2) aged between 16-65 years (3) 4 to 6 weeks after bone fracture surgery, 8 weeks post flexor tendon repair surgery, and amenable to progressive resistance movement; and (4) no communication or cognitive deficits. Clients were excluded from the study if they had: (1) bilateral hand injuries; (2) in conjunction with other injuries, such as peripheral nerve injuries, shoulder or elbow injury; or (3) wound was not healed.

Eligible subjects were randomly assigned to the experimental group (receiving computer-assisted wrist/hand strengthening training) and control group (treated with conventional therapy). A staff member not involved in the study was responsible for the allocation by using a computer generated random number table.

Description of computer-assisted wrist/hand rehabilitation system

The hardware components of a computer-assisted wrist/hand rehabilitation system consisted of a desk-top computer, a handmade joystick handle with seven force sensing resistors on its surface and a data processing module (**Figure 1**). In order to suit different degrees of thumb carpometacarpal joint abduction range of motion (ROM) of participants, the joystick handle was made into an ellipsoid shape. Pinch force of the affected fingers was selectively sampled and served as an input signal to control the virtual scene.

A virtual shooting video game was used to train both wrist and hand in an integrated manner (**Figure 1**). The participants were asked to grip the handle, then to move forearm and wrist so as to hit targets. When the average pressing force applied to the selected sensors was greater than firing force threshold (set by the therapist on trying basis), the "tank" would open fire at the target and finally destroyed it. During the training process, the total number of hit targets and the average strength applied would be displayed on the screen in real-time fashion (**Figure 1**). In addition, positive feedback in the form of encouraging remarks

Figure 1. A subject is using the computer-assisted wrist/hand training apparatus. The photograph at bottom left shows the locations of force sensing resistors (FSRs).

(sounds and images) was immediately given when the target was hit.

Intervention protocol

Over a 4-week intervention period, participants in both the experimental group and control group received a total of 40 sessions of intervention. Two intervention sessions were given a day, a total of 60 min each session, and all on weekdays.

All participants performed 40 min of the following exercises for one session: (1) physical modalities and (2) ROM exercises. Physical modalities included thermal modalities and ultrasound, which aimed to decrease pain and reduce soft tissue adhesion. ROM exercises were composed of joint mobilization and tendon gliding. If a tendon was adhering, the clients were instructed actively in exercises to facilitate tendon gliding, such as hook, straight fist and fist, as well as isolated exercises to assist tendon gliding. While a joint was stiff, passive ROM exercise was done by the therapist, such as joint mobilization. Appropriate splinting techniques were effective for joint contracture.

After the above physical modalities and ROM exercises, all participants received a 20-minute of strengthening exercises, aimed to improve wrist and hand strength. Subjects in the experimental group received computer-assisted wrist/hand strengthening training using our designed apparatus. The level of difficulty could be adjusted by changing the firing strength threshold or the movement speed of the handle when patients' performance improved. While participants in the control group were given conventional strengthening exercises, by using Theraband for wrist exercises and therapy putty for hand grip/pinch strengthening. The intensity of exercises and the repetitions would adapt to the participants' individual condition and resistance progressively increased. The strengthening exercises lasted for 20 min for each session, and all these sessions were engaged under the guidance of the same therapist.

Baseline and post-intervention assessment

Demographic characteristics, such as age, gender, occupation, injured side, handedness, cause of injury, type of injury, etc, were documented in both groups of patients. All the participants were assessed at baseline and post four weeks of intervention by a trained and experienced rehabilitation physician, who was blinded to group allocation. The outcome measures were: (1) Total Active Motion (TAM) [18]; (2) Grip strength; (3) Pinch strength (two-point pinch, key pinch and three-point pinch) [19]; (4) Nine-hole pegboard test [20] and (5) Upper Extremity Functional Index (UEFI) [21].

Total active motion (TAM)

TAM measured in composite flexion and extension indicated the functional limitations of

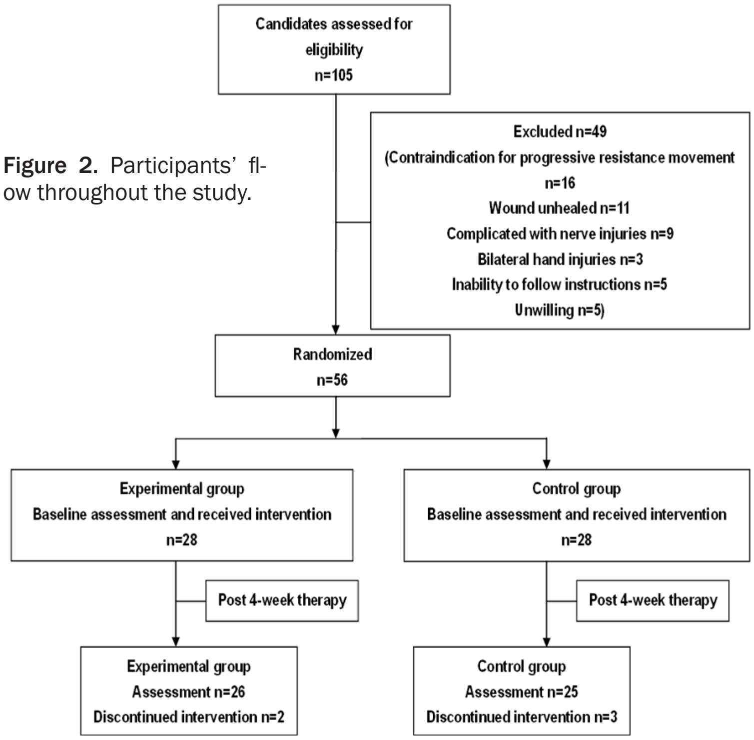

Figure 2. Participants' flow throughout the study.

motion. TAM was measured using a finger goniometer while the wrist at 0-degree neutral, and the forearm and hand supported on a firm surface on the ulnar border. All measurements were conducted according to the standardized protocol. TAM was computed by adding the sum of all active flexion angles of digit and thumb joints, minus incomplete active extension of the digits and thumb joints.

Grip strength

The grip gauge (Biometrics Ltd., Newport, United Kingdom) was a standard adjustable-handle tool for assessing grip strength. The subject was asked to sit with shoulder adducted and neutrally rotated, elbow flexed at 90 degrees, forearm in neutral position and wrist between 0 and 30 degrees extension. With the dynamometer handle set at the second position, three measurements were taken each time and the average was used.

Pinch strength

The pinch gauge (Biometrics Ltd., Newport, United Kingdom) was used to assess two-point pinch (thumb tip to index fingertip) strength, lateral pinch (thumb pulp to lateral aspect of the middle phalanx of the index finger) strength, three-point (thumb tip to tips of index finger and middle fingers) pinch strength. The position of measurement was similar to that used in grip strength. Three trials were taken and the average was calculated for the analysis.

Nine-hole pegboard test

Nine-hole pegboard test (Smith & Nephew Rehabilitation, Inc.) was developed to assess hand dexterity. Tests were conducted by following standard instructions. The test was timed by using a stopwatch, starting from the moment the participant touched the first peg and ending when the last peg was put back to the tray. The test was repeated two times and the average time of two tests was calculated and recorded.

Upper extremity functional index (UEFI)

UEFI was developed for self-assessment of upper extremity function, with good psychometric properties. UEFI includes 20 function items, which can be completed (3-5 minutes) and scored (only 20 seconds) in shorter time, compared with Disabilities of Arm, Shoulder, and Hand (DASH). It is graded from 0 (extreme difficulty or unable to perform activity) to 4 (no difficulty to perform activity). The final UEFI score was calculated by adding the score of each item. Lower the score, more severe the disability.

Statistical analysis

Data were analyzed with SPSS Version 19.0 (IBM Corporation, Armonk, NY). Independent sample *t*-test, Fisher's exact test and *Chi*-squared test were used to determine differences in participants' characteristics and baseline values between groups. Repeated-measure analysis of variance (ANOVA) was used for evaluating the main effects of time, group and the group-time interaction effects. Level of significance was set at $P<0.05$ (two-tailed).

Table 1. Characteristics of participants

	Experimental Group (n=26)	Control Group (n=25)	p^a
Age, years (M ± SD)	33.44±13.23	33.50±12.07	0.989
Gender, n (%)			0.301
Male	14 (54%)	17 (68%)	
Female	12 (46%)	8 (32%)	
Occupation, n (%)			0.910
Manual work	11 (42%)	9 (36%)	
Office work	7 (27%)	8 (32%)	
Student	2 (8%)	3 (12%)	
Farmer	6 (23%)	5 (20%)	
Injured hand, n (%)			0.886
Dominant	13 (50%)	13 (52%)	
Non-dominant	13 (50%)	12 (48%)	
Cause of injury, n (%)			0.768
Twist injury	15 (58%)	13 (52%)	
Incise injury	10 (38%)	10 (40%)	
Domestic	1 (4%)	2 (8%)	
Type of injury, n (%)			0.910
Fracture	9 (35%)	10 (40%)	
Flexor tendon	12 (46%)	11 (44%)	
Fracture & Flexor tendon	5 (19%)	4 (16%)	
Post-injury time, days (M ± SD)	51.25±15.21	46.50±13.71	0.621

Note. [a]Chi-squared test or Fisher's exact test for categorical variables (two-tailed); independent sample t tests for continuous variables (two-tailed).

Results

Characteristics of included patients

One hundred and five patients diagnosed with traumatic hand injuries involving bone and flexor tendon injuries were initially included. Forty nine patients were excluded against the inclusion criteria. Then, a total of 56 eligible subjects were selected for the study and were randomly assigned to two groups (28 in each). During the 4 weeks of intervention, three individuals in the control group withdrawn (2 because of family affairs, and 1 underwent an operation), and two participants in the experimental group dropped out (one owing to medical insurance, and the other because of preparing graduation examination). Finally, a total of 51 participants completed the 4-week treatment sessions and their data were analyzed (**Figure 2**).

The experimental group was consisted of 26 patients (14 M, 12 F) with a mean age of (33.44±13.23 years), while 25 patients (17 M, 8 F) with a mean age of (33.50±12.07 years) were in the control group. The two groups were similar with respect to the post-injury time (51.25±15.21 versus 46.50±13.71). The demographic features of all the participants are presented in **Table 1**. No significant differences (P>0.05) were found between the groups in occupation, injured hand, cause of injury or types of injury. The baseline outcome measures in both groups are showed in **Table 2**, and were similar at the baseline evaluations of TAM, grip and pinch strength, nine-hole pegboard test and upper extremity function index scores (all P>0.05).

Outcome before and after intervention

A repeated measure ANOVA at baseline and at the end of the clinical trial revealed significant improvement for both groups in all the tests (all P<0.05), while no group effect was detected for any test variable (all P>0.05). However, significant group-by-time interaction effects were only demonstrated in grip strength (P=0.001), lateral pinch strength (P=0.026), NHPT (P=0.041) and UEFI scores (P=0.023) (**Table 2**). Post hoc analysis showed that participants in the trial group made greater improvements after treatment in these variables (grip strength: 3.51±0.35 versus 1.54±0.37; lateral pinch strength: 0.70±0.12 versus 0.32±0.12; NHPT: -18.67±3.70 versus -8.13±3.95; UEFI scores: 15.92±2.50 versus 7.31 ±2.50) compared to the control subjects.

Safety

All participants showed no serious adverse reactions during the treatment. Only one case in the experimental group complained of mild pain in the contact area between his finger and the joystick. But after re-setting the difficulty level of the game, the pain disappeared within few minutes.

Table 2. Outcome measures before and post-treatment and change levels

	Baseline (means ± SD)	Post-intervention (means ± SD)	Change Level	*F* value	*P*
TAM (degree)					
Control group	745.00±228.11	802.50±210.57	57.50±78.58		
Experimental group	729.17±238.92	789.16±191.35	60.00±54.68	0.004	0.954
GS (Kg)					
Control group	5.88±2.38	7.42±2.69	1.54±0.37		
Experimental group	5.54±3.47	9.05±3.74	3.51±0.35	15.184	0.001*
Two-PS (Kg)					
Control group	1.13±0.49	1.38±0.51	0.25±0.13		
Experimental group	1.26±0.33	1.86±0.50	0.60±0.53	1.629	0.243
LPS (Kg)					
Control group	1.60±0.79	1.92±0.95	0.32±0.12		
Experimental group	1.39±0.65	2.09±0.82	0.70±0.12	5.490	0.026*
Three-PS (Kg)					
Control group	1.10±0.65	1.52±0.99	0.42±0.44		
Experimental group	1.20±0.66	2.14±0.49	0.94±0.93	1.252	0.296
NHPT (s)					
Control group	47.17±25.73	39.04±24.02	-8.13±3.95		
Experimental group	52.57±27.89	33.90±17.07	-18.67±3.70	3.589	0.041*
UEFI scores					
Control group	48.85±12.69	56.15±13.03	7.31±2.50		
Experimental group	45.00±16.22	60.92±12.04	15.92±2.50	5.933	0.023*

Note: TAM, total active motion; GS, grip strength; Two-PS, two-point pinch strength; LPS, lateral pinch strength; Three-PS, three-point pinch strength; NHPT, nine-hole pegboard test; UEFI, upper extremity function index. *$P<0.05$ represents statistically significant for group-by-time interaction effect.

Last, but not least, all the patients remarked that computer-assisted wrist/hand training was interesting and motivating.

Discussion

Computer-assisted intervention allows a user to interact with a computer-simulated environment, which provides near real-time feedback on performance [22]. However, limited evidence exists regarding the effects of video games in traumatic hand injuries rehabilitation [11, 23]. The clinical study presented in this paper suggests that the computer-assisted wrist/hand therapy is feasible, safety, and can achieve better hand functional recovery, particularly in hand strength and dexterity, as compared to conventional intervention.

A significant time effect was observed for all measures, but no significant differences were observed after intervention between the control and experimental groups in TAM, which suggested that both types of strengthening exercises combining with ROM exercises were all effective in improving TAM. This may be ascribe to the fact that the computer-assisted system is designed to train hand strength more specifically than range of motion (ROM) of fingers. Since ROM is not specially trained in this computer-assisted system, computer-assisted strengthening exercises have no significant effect in ROM, comparing with conventional strengthening training.

In both groups, hand strength (measured in terms of grip and lateral pinch strength) was significantly improved after 4-week training, but the experimental group showed even better therapeutic effects than the control group (the mean change level for grip strength is 3.51 versus 1.54, while for lateral pinch strength is 0.70 versus 0.32). It is commonly recognized that feedback of one's performance is critical for motor learning in neurological rehabilitation [24]. Rehabilitation training, in conjunction with feedback, can better improve the effect of motor learning as compared with conventional training [25]. Evidence also showed that feedback could enhance learning efficiency [26]. As in this study, the computer-assisted training could provide real-time training performance feedback, as well as positive feedback in the form of encouraging remarks (sounds and images). This might be one of the reasons that patients in the computer-assisted therapy performed better in lateral pinch and grip strength compared to the conventional intervention. Meanwhile, computer-assisted therapy using video gaming is more interesting and thereby could motivate participants to engage in training [27]. Moreover, difficulty levels of the computer-assisted training are adjustable to adapt to patients' function. Attractive games together with proper task difficulty are essential to maintain a patient's motivation and compliance [28, 29]. Thus, the intensity of repetition training is guaranteed, which provides an important way to improve motor ability [30].

Compared with lateral pinch strength, which is used to measure pinch strength, two-point and three-point pinch strength are weaker and relatively more difficult to test [31]. The results showed that after intervention no significant difference was observed for two-point or three-point pinch strength between the two groups. This may be due to the fact that limited flexion angles of digit and thumb joints possibly interfered with two-point or three-point pinch strength testing.

Assessment of the progress in the nine-hole pegboard test, even though both groups showed improvement over time, significant a better course of recovery on hand dexterity for participants in the experimental group was found. Evidence showed that training the hand-arm together, which was closer to the daily life of the patients, could improve the functional use of the affected hand post-stroke [32]. The wrist is the key to the function of the hand. Positioning of the hand for functional tasks relies on the stability, mobility, and precision of placement permitted by the wrist. Similarly, the system designed in our study is to train the wrist and hand in an integrated manner, also improve hand-eye coordination, thus resulted in better progress in hand dexterity compared with conventional treatment. In addition, compared with E-Link system, which trains grip and pinch strength separately [11], training involving both wrist and hand in this system is more challenging and interesting.

With measures of hand rehabilitation outcome, apart from impairment (e.g., strength, motion), it is of great importance to measure disability and function. In our study, participants in both groups acknowledged improved upper extremity function over the course of training, but the experimental group showed even higher scores in UEFI than the control group. UEFI is self-administered questionnaire, which reflects the upper extremity function [21]. Meanwhile, it is easily affected by the patients' psychology. In this computer-assisted training course, real-time training performance and encouraging feedback could greatly inspire patients and increase their confidence [33]. Therefore, training effects of this system naturally transfer to real life, resulted in more confidence in performing daily activities.

Compared with conventional treatment, the cost of computer-assisted rehabilitation therapy is relatively low. Moreover, this simple system, which combines modified joystick and force sensing resistors, is easier to control and maintain. Therefore, it might be popularized for home use. The current study has some limitations. Firstly, the sample is focus on traumatic hand injuries involving bone and flexor tendon, and trials on other types of hand injuries should be conducted to provide further evidence for the effectiveness of this computer-assisted hand rehabilitation system. In addition, longer follow-up will also be necessary to determine the transfer effect of computer-assisted therapy into reality.

Conclusion

Computer-assisted wrist/hand intervention exhibited better results in improving hand strength and dexterity for hand injuries. It might be an alternative treatment for hand injuries in both clinical and home-based rehabilitation practice.

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Disclosure of conflict of interest

None.

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