



Original Article

Application of RFID technology—upper extremity rehabilitation training

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Abstract. [Purpose] Upper extremity rehabilitation after an injury is very important. This study proposes radio frequency identification (RFID) technology to improve and enhance the effectiveness of the upper extremity rehabilitation. [Subjects and Methods] People use their upper extremities to conduct daily activities. When recovering from injuries, many patients neglect the importance of rehabilitation, which results in degraded function. This study recorded the training process using the traditional rehabilitation hand gliding cart with a RFID reader, RFID tags in the panel, and a servo host computer. [Results] Clinical evidence, time taken to achieve a full score, counts of missing the specified spots, and Brunnstrom stage of aided recovery, the proximal part of the upper extremity show that the RFID-based upper extremity training significantly and reduce negative impacts of the disability in daily life and activities. [Conclusion] This study combined a hand-gliding cart with an RFID reader, and when patients moved the cart, the movement could be observed via the activated RFID tags. The training data was collected and quantified for a better understanding of the recovery status of the patients. Each of the participating patients made progress as expected.

Key words: Rehabilitation, RFID, Hand-gliding cart

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INTRODUCTION

In the modern, tense, busy environment, sudden incidents, car accidents, and occupational injuries can easily cause severe body impairment, and strokes and spinal injuries result in many becoming physically impaired. Following recovery from injury, many patients may still suffer muscle atrophy due to lying in bed for too long, and through lack of attentive care of their body condition. This post-recovery syndrome may result in gradual degradation of the original muscle functions and ultimately, lead to difficulties in movement and rehabilitation. Therefore, it is very important to provide patients with effective post-recovery rehabilitation.

Most physical human actions involve the use of the upper extremities. According to the U.S. National Security Agency, one-third of occupationally impaired body functions are in the upper extremities¹⁾. In its functional disability standards, the American Medical Association identifies losing one arm as equivalent to losing 60% of the body mechanism, and the loss of a hand equates to the loss of 90% of the arm function or 54% of the entire body mechanism²⁾. Apparently, having healthy upper extremities is an important issue.

Generally, patients with upper extremity disability need to use rehabilitation equipment for repetitive training, to have the best chance of recovering full function of the extremity. There are a variety of upper extremity rehabilitation therapies. The

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one seen most commonly uses mechanical arms to guide patients during passive or active training. Kreb used a mechanical arm MIT-MANS of his own creation to rehabilitate 20 stroke patients³). In this treatment, a video-game-type interface on a screen is used to guide the patients to move the mechanical arms to help them rehabilitate their auxiliary nerves. Szturm suggests that using a volleyball and toys easily available in daily life, together with sensors and video games, can make the rehabilitation process much more fun and lively, and the training data can be quantified. With a custom-made mechanical device⁴), J. Alastair Cozens put the patients' impaired upper extremity on a controlling lever⁵), and during the rehabilitation process, the upper arm is fixed, while the forearm makes 10 to 80 degree flexion/stretching movements guided by a blinking light at the front. This mechanical device can provide feedback on movement distance, measured by a electronic protractor and accelerometer, and use it as a parameter for a servomotor to adjust the pushing and pulling force applied to the rehabilitative movement. Gui Bin Song recommended bilateral arm training as well as functional task training in clinical interventions' to improve upper limb functional activities of daily living of patients with hemiplegia⁶). The above upper extremity rehabilitation systems can collect detailed training data; however, their common problem is their high implementation cost and their size, which is too large to be portable. Y-S Hwang et al. used a magnetic sensor and reed switches to track the movement of the upper extremity during rehabilitation training⁷). Toshiaki Tanaka suggested that a virtual environment system might be effective at facilitating motor relearning of the upper extremity for stroke patients⁸). Kyoung-Hee Lee reported that a virtual reality exercise program was effective at restoring the function of stroke patients⁹). Seong-Sik Kim showed that motor imagery training has a positive influence on upper extremity performance by improving functional mobility during stroke rehabilitation¹⁰). Jungseo Park et al. suggested that virtual reality exercise using the Nintendo Wii Fit is an effective intervention for the muscle activities of the TA and MG of normal adults¹¹). Shogo Hiragami et al. suggested that mirror therapy in addition to a conventional rehabilitation program can be effective for finger motor dysfunction after stroke¹²). Another common rehabilitation approach is to use simple physical movement therapy, even though its recovery efficacy is subjective. Computer-aided rehabilitation can help patients with upper extremity disability perform easy, relaxing, and systematic rehabilitative exercises, and the training data can be quantified and saved in a database for later medical use. Digital processing enables medical personnel to better understand patients' recovery conditions, and to conduct long-term tracking. Furthermore, the data can be very helpful in clinical diagnosis.

In this study, a simple approach to rehabilitation was taken to help patients recover upper extremity function. The equipment used was a panel of RFID tags, a computer server, and a hand-gliding cart with an RFID reader. When a patient moves the hand-gliding cart across the panel, the screen automatically displays the route taken by the gliding cart, and the route spots during the course of the movement are recorded for quantification. This auxiliary device, developed for this study of rehabilitation training, can actually help patients stretch their impaired upper extremities, prevent continual upper extremity atrophy, and reduce the negative impact of disability on daily life and activities.

SUBJECTS AND METHODS

The purpose of this study was to help patients with the rehabilitation of their upper extremities. With the helping force of the gliding cart, patients moved their hands, which stretched their upper extremities, facilitating rehabilitation.

Figure 1 demonstrates a traditional hand-gliding cart for upper extremity rehabilitation. The therapist is beside the patient to provide guidance. However, the training data in the course of rehabilitation cannot be recorded.

Figure 2 demonstrates the overall conceptual diagram of this study. There is a matrix of RFID tags beneath the panel for the extremity rehabilitation training, and at the bottom of the hand-gliding cart, there is an RFID reader. When the patient glides the cart across the panel, it causes the RFID tags to react, and a reactive message is sent to a computer server, which calculates the coordinates. These positional coordinates are stored in a database for calculation of the training scores. A dragger is connected to the hand-gliding cart via a traction line, and this dragger is used to adjust the pulling force on the traction line. Patients participating in the training first finish medical record authentication, and then proceed to rehabilitation training. The patient puts the functionally impaired hand on the handle of the hand-gliding cart (1) to move the cart, and the RFID tags (2) along the route of the cart's movement are activated and their data is read by the RFID reader (3) and sent to the server (4) for calculation of the trajectory (∞) and to be saved in the database (5). The panel incorporates 30 rows \times 20 columns of RFID tags which are used to monitor the trajectory (∞) of the cart. The hand-training unit provides an illustration of the actions. The back of the patient's hand is fixed with Velcro when the patient's palm is placed precisely on the cart's handle for pushing the gliding cart.

The RFID tag is small, light, and resistant to external interference, which makes it very suitable for use in a limited-space environment.

The diagram in Fig. 3 shows the training implemented in this study: (1) the hand-gliding cart used for training and testing, (2) the specific route patterns displayed on the screen as training and testing guidance, and (3) the moving tracks of the gliding cart. The cart is displayed in blue when it moves correctly along the specified route, and is red otherwise. Furthermore, the right side of Fig. 3 shows three specific routes with differing widths along which the cart, displayed as red or blue, moves.

The tracks displayed on the screen allow visual inspection for a comparison with previous results (records of the tracks), and they can be set into the predefined background track map (specified route map). When loading multiple records of tracks, they can be distinguished by user-defined or system-default colors, and the multiple tracks of movement displayed on the



Fig. 1. Traditional hand-gliding cart for upper extremity rehabilitation

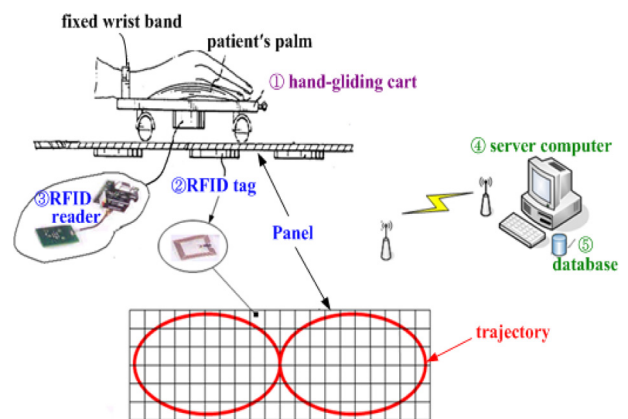


Fig. 2. Overall conceptual diagram

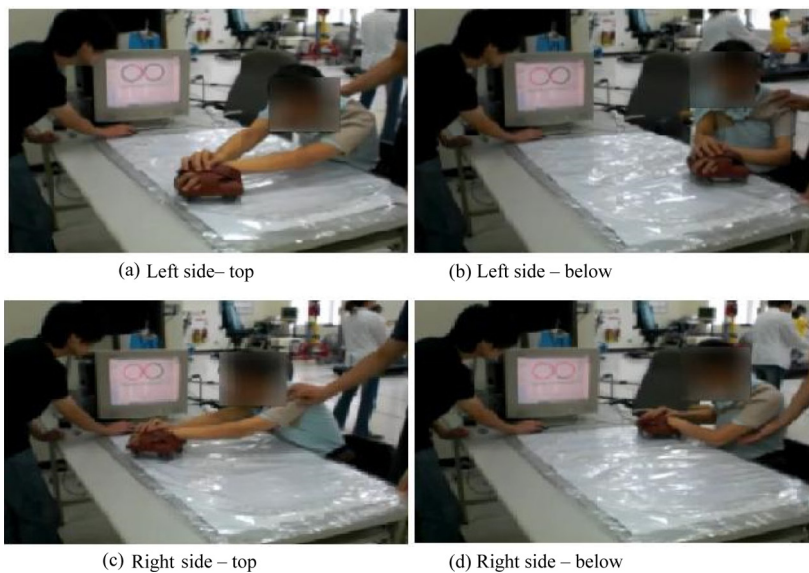


Fig. 3. Implementation

screen can be compared visually to allow the rehabilitator to adjust the training program.

The participant needs to finish the identification authentication before the rehabilitation commences. The screen displays specific patterns for the participant to copy when moving the cart. The training data are transmitted to a computer server for the calculation of the number of trajectory errors and the time taken, as well as for data storage.

The experiments performed in this study had two parts: testing with subjects with normal upper extremity functions and testing with subjects with upper extremity impairments. The 6 normal participants (Table 1) used their upper extremities to glide the cart across the panel and the computer system recorded the coordinates of the track and performed a statistical analysis, which can be referenced by medical personnel.

The 6 participants with normal upper extremity function conducted ten rounds of the training and testing with the RFID-based training system developed for this study. The collected training data were analyzed to examine the variation before and after the training to determine whether the system could provide consistent evaluations of the extremity usually used, and to make sure that the system was stable with high repeatability¹³⁻¹⁶.

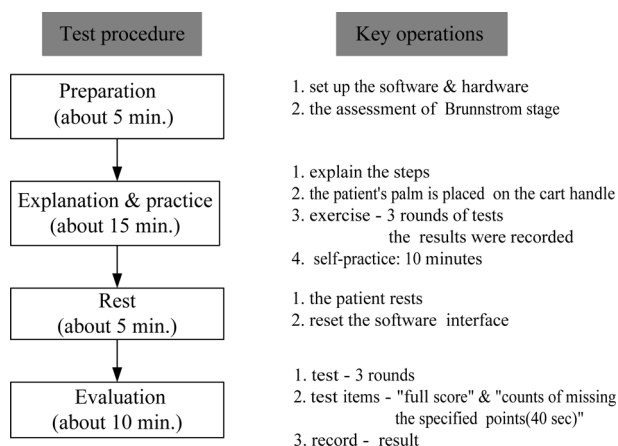
The 10 participants with upper extremity impairments (1.5–2.5 years after stroke, vital sign stable, and Mini-Mental State Examination scores >27), Table 2 performed twice-weekly training and testing sessions for four consecutive weeks. The participants did not receive any physical or occupational therapy for the affected upper extremity during the course of the study, and they were asked not to receive botulinum toxin injections in the 12 weeks prior to and during their participation in this study. For these stroke patients, so a Brunstrom Stage assessment of motor recovery was performed, to determine their upper extremity mobility, that an appropriate training program could be arranged¹⁷⁻¹⁹. Figure 4 shows the schema of

Table 1. Basic information of the normal participants

Items	Data
Participants	6
Age (mean \pm SD)	58.6 \pm 8.6
Male / Female	3/3
Height (cm)	165.8 \pm 7.8
Weight (kg)	65.4 \pm 8.8

Table 2. Basic information of the participants with upper extremity impairment (P1–P10)

Item	Data
Number of participants	10
Age (years)	61.7 \pm 9.2
Male / Female	7/3
Height (cm)	164.3 \pm 9.1
Weight (kg)	70.2 \pm 8.5

**Fig. 4.** Schema of the experiment

the experiment. Before an exercise was practiced, there were three rounds of tests and the results were recorded. Then, the patients performed self-practice exercises for ten minutes, before completing another three tests for the record.

The pre- and post-training results, time taken to achieve a full score and counts of missing the specified spots, of the 10 participants with upper extremity impairments were compared using the paired-t test. The SPSS predictive analytics software for Windows was used for statistical analysis in this study.

The ethical committee of the Taipei Medical University Hospital approved the studies and written informed consent was obtained from each participant.

RESULTS

This experiment used two groups of subjects for cross-verification: one group had normal upper extremity function and the other had impaired upper extremities. The participants used their hands to glide the cart displayed on the panel, and the computer system recorded the track coordinates of the moving cart and analyzed the data for the medical personnel. To verify the stability of the system, 6 participants with normal upper extremity function performed the system tests.

The RFID tags are arranged in a matrix pattern for optimum tracking of the coordinates of the moving cart. Arrangements of a single layer, dual layers (inner and outer), and triple layers were constructed to observe and verify the impact on the usually used upper extremity. Table 3 shows the averages of ten consecutive rounds of tests conducted by the normal participants. From the scores, it can be seen that the usually used upper extremity had the better performance. Also, the average scores (counts) of incorrect movements of the cart (not along the specified track) in the single-layer test ranged from 1.5–1.9 times, for the 6 normal participants using their dominant side hands, which was as expected. This result is an ideal outcome for those with normal upper extremity function and it is certainly good for those with upper extremity impairment.

The 10 participants with upper extremity impairment had Brunnstrom stages of the proximal part of the upper extremity between III and IV, indicating a recovery level of self-controlled movement. Thus, the training focused on the manipulation of self-controlled movement at various angles and directions. The clinical assessment results revealed steady progress, indicating that muscle tension of the subjects was approaching normal and that their isolated movement was becoming mature. Overall, each participant showed significant improvements ($p < 0.05$) after-training in terms of the time taken to achieve a full score (Test 1) and counts of missing the specified spots (Test 2), as shown in Table 4. Participants P1, P5 and P9 showed changes in their Brunnstrom stage of the proximal part of the upper extremity from category IV to V. Participants P2, P3 and P6 also showed changes in their Brunnstrom stage of the proximal part of the upper extremity from category IV to V, but their

Table 3. Averages of 10 consecutive rounds of tests conducted by the normal participants

Participants	Gender	Dominant side	incorrectly specified location		Average time (sec)	
			average times		full score	
			left hand	right hand	left hand	right hand
A	Male	right hand	2.1	1.8	24.6	19.8
B	Male	right hand	2.1	1.6	24.2	20.3
C	Female	left hand	1.9	2.5	20.5	25.1
D	Male	right hand	2.1	1.7	26.1	20.2
E	Male	right hand	2.3	1.5	23.8	21.6
F	Female	left hand	1.5	2.2	20.1	24.2

Bold shows the best performances

Table 4. The clinical testing results of the participants with upper extremity impaired (P1–P10)

Participants	Gender	Test 1		Test 2		Test 3
		Pre-training	After-training	Pre-training	After-training	Pre-training → After-training
P1	Male	41.2	35.2*	3.33	1.98*	IV →V
P2	Male	56.8	52.1*	6.21	4.53*	IV →V
P3	Female	57.2	52.6*	6.39	4.61*	IV →V
P4	Female	68.2	63.5*	8.23	6.87*	III→ IV
P5	Male	42.3	37.5*	3.48	2.01*	IV →V
P6	Female	58.7	53.1*	6.58	4.78*	IV →V
P7	Male	68.7	64.2*	8.38	6.92*	III→ IV
P8	Male	70.1	68.3*	8.49	7.02*	III→ IV
P9	Male	41.9	36.3*	3.39	1.99*	IV →V
P10	Male	69.8	66.5*	8.36	6.95*	III→ IV

Test 1: Time taken to achieve a full score

Test 2: Counts of missing the specified spots

Test 3: Brunnstrom stage of the proximal part of the upper extremity

*paired t-test, $p < 0.05$

performances in the 3rd and 4th weeks showed no progress, probably due to their older ages resulting in reduced physical strength and weaker responsiveness. Thus, rectification of their inappropriate movement had little effect. Participants P4, P7, P8 and P10 showed changes in their Brunnstrom stage of the proximal part of the upper extremity from category III to IV, and their performance in the first three weeks in terms of the “time taken to achieve full score” and “counts of missing the specified spots” showed steady progress. However, the results remained the same in the 4th week, which indicates that their muscles tensions were reducing, but that their capability of self-controlled extremity activity had improved and therefore, the chance of isolated movement had also improved.

DISCUSSION

This study combined a gliding cart with an RFID reader, and when patients moved the cart, its track was recorded via the activated RFID tags. Training data was collected and quantified for a better understanding of the recovery status of the patients. Each of the participating patients made progress as expected.

The movement trajectory (tracks) can be adjusted in clinical experiments depending on the patient’s condition. That is, when the patient’s upper extremity is more severely impaired, the ∞ -shaped trajectory can be easily modified by changing the settings of the computer server, so that the patient can be encouraged to continue with the training. In addition, funny games can be added to the training program to make the training more lively, and the rehabilitation effect can be improved^{20, 21}.

When extremities are paralyzed, rehabilitation should be started as soon as possible for a better recovery effect, and for gaining an exercise pattern closer to normal movement. In the beginning, a patient can exercise the normal extremity to trigger the impaired one to move. That is, making use of the simultaneousness and interchangeableness of the two upper extremities to repeat the training exercises, so that movement of the impaired extremity can be triggered. Most importantly, persistent practice is the best way to achieve a good rehabilitation result.

This study was subject to several limitations. Participants were reporting no progress with activities of daily living using the affected upper extremity, no control group was included in the study, and other factors such as the maturation effect and possible rater bias in the evaluation, may have affected the results. Replication of this study with a larger sample size, longer treatment period, and use of a placebo group in a randomized controlled trial is desirable. A study of the long-term effects of this treatment should also be conducted by establishing follow-up period.

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