Task-oriented mirrored upper-limb robotic training in subacute patients after stroke: a case control study

Jingsong Wu  
Fujian University of Traditional Chinese Medicine

Zhenming Huang  
Fujian University of Traditional Chinese Medicine

Haiyin Deng  
Fujian University of Traditional Chinese Medicine

Youze He  
Fujian University of Traditional Chinese Medicine

Jia Huang (✉ jasmine1874@163.com)  
Fujian University of Traditional Chinese Medicine

Jianhuang Wu  
Fujian Collaborative Innovation Center for Rehabilitation Technology

Research Article

Keywords: Stroke rehabilitation, Robotic rehabilitation, Subacute stroke, Upper limb, Training device, Task-oriented, Neurorehabilitation

Posted Date: December 7th, 2022

DOI: https://doi.org/10.21203/rs.3.rs-2337660/v1

License: ☝️ ☑️ This work is licensed under a Creative Commons Attribution 4.0 International License.  
Read Full License
Abstract

Objective

People with stroke often have upper limb motor impairment, which has an impact on their activities of daily living and quality of life. Robotic-assisted training devices are used for upper limb rehabilitation, but their effectiveness in enhancing activities of daily living is not satisfactory yet. In this study, we combined task-oriented training and mirror training to an upper limb robot, created a task-oriented mirrored upper limb robot (Wisebot X5), and investigated the feasibility and safety of task-oriented mirror robot training for subacute stroke patients and observed its effects on upper limb motor function and activities of daily living.

Methods

Based on case-control principles, 32 patients with subacute stroke were assigned to receive task-oriented mirrored upper limb rehabilitation robot training for 30 minutes each time, 5 times per week for 4 weeks, or to receive the equivalent duration of conventional occupational therapy training. The primary outcome was the Fugl-Meyer Assessment of the Upper Extremity (FMA-UE), and secondary outcomes were the Modified Barthel Index (MBI), the Stroke Self-Efficacy Scale (SSEQ), the System Usability Scale (SUS), and the Chinese version of the Quebec User Evaluation With Assistive Technology (C-QUEST). Statistical analysis was performed with paired-samples t-test.

Results

Thirty-two patients participated and completed the study. After the 4-week intervention, for FMA-UE, the experimental group was better than the control group in terms of the change score from the baseline to post intervention (P < 0.05). For MBI and SSEQ, both the experimental and control groups showed significant increases after the intervention (P < 0.05). However, there was no statistical difference between the groups in terms of the change score from the baseline to post intervention (P > 0.05). The usability assessment reported a high level of satisfaction: mean SUS score is 74.84% (SD = 11.64), mean QUEST scale is 4.42 (SD = 0.31).

Conclusions

Task-oriented mirrored upper-limb robotic training is feasible and safe for patients with subacute stroke. It is beneficial in promoting the recovery of upper limb function and activities of daily living.

1 Introduction
Stroke is the most common cause of death and disability worldwide (Feigin et al., 2017; GBD 2019 Stroke Collaborators, 2021; Thayabaranathan et al., 2022). About 80% of stroke survivors have upper limb motor impairment (4), which seriously affects their activities of daily living and quality of life (Pollock et al., 2014; Stinear et al., 2020; Schindel et al., 2021; Yuliana et al., 2022). Studies have shown that upper extremity recovery is faster in patients with subacute stroke than in those with chronic periods (Dobkin and Carmichael, 2016; Bernhardt et al., 2017), making the subacute period an essential period for upper extremity rehabilitation in stroke (Dobkin and Carmichael, 2016; Bernhardt et al., 2017).

Previous studies have shown that upper extremity robotics can help patients with motor function rehabilitation (Conroy et al., 2019; Dehem et al., 2019; Rosenthal et al., 2019; Aprile et al., 2020; Carpinella et al., 2020; Lee et al., 2020). Cochrane systematic reviews have shown that electromechanical and robot-assisted arm training can help improve arm function and muscle strength in post-stroke patients (Mehrholz et al., 2018). However, the effect of improving patients' activities of daily living is unclear. Subgroup analyses showed that electromechanical and robotic-assisted training improved the score of activity of daily living in patients within three months of stroke but not in patients with a stroke longer than three months (Mehrholz et al., 2018). A multicenter clinical trial including 770 patients found that robotic-assisted training improved the score of the Fugl-Meyer Assessment of the Upper Extremity compared with usual care, but this did not translate into improvements in activities of daily living (Rodgers et al., 2019). It has also been suggested that the development of new upper limb robots should focus on the restoration of upper limb muscle strength as well as the improvement of movement patterns and activities of daily living (Mehrholz et al., 2018; Conroy et al., 2019; Rodgers et al., 2019).

Studies have shown that task-oriented training and mirror training can improve upper extremity function and activities of daily living in stroke survivors (French et al., 2016a; Bondoc et al., 2018; Thieme et al., 2018; Gandhi et al., 2020; Choi, 2022; Hussain et al., 2022; Rungseethanakul et al., 2022). Task-oriented training integrates tasks commonly used in various activities (e.g., holding a cup to drink, dressing) into a rehabilitation program (Bayona et al., 2005; Hubbard et al., 2015a; French et al., 2016). These tasks focus on improving the functional performance of the upper extremity through goal-oriented exercises and repetitions and allow patients to acquire basic activities of daily living. A meta-analysis that combined 33 studies with 1853 subjects showed that task-oriented upper extremity functional training facilitated the recovery of upper extremity function while also improving activities of daily living in patients with stroke (D’Anci et al., 2019). At the same time, the activities of daily living tasks require the coordination of both hands, and unilateral hemiparesis can seriously affect the coordination of hands, which affects the completion of activities of daily living tasks (Veerbeek et al., 2014). Mirror therapy promotes the rehabilitation of the hemiplegic limb by reflecting images from the non-affected side to the affected side, creating the illusion of normal movement of the affected limb (Ramachandran et al., 1995a; Deconinck et al., 2015a). Mirror therapy helps patients recover upper limb function while increasing the sensory input of simultaneous movements of both hands, facilitating the recovery of activities of daily living. Systematic reviews have shown that mirror therapy improves upper extremity dexterity, gross and fine motor function, and proximal motor control and decreases motor time (Gandhi et al., 2020). A meta-
analysis including 62 studies with 1982 subjects also showed a significant positive effect of mirror therapy on motor function and activities of daily living (Thieme et al., 2018).

There have been studies attempting to apply task-oriented and mirror training to design upper limb rehabilitation robots, respectively. Task-oriented upper limb rehabilitation robots (Klamroth-Marganska et al., 2014; Chen et al., 2021) and robotic mirror therapy systems (J et al., 2016; Yang et al., 2021; Wei et al., 2022) have been developed. However, there are no upper limb robots that combine both types of training at the same time. The combination of task-oriented training and mirror training to facilitate the performance of activities of daily living may be more useful for the rehabilitation of stroke patients. For this purpose, we devised a task-oriented mirrored upper limb robot (Wisebot X5) by integrating task-oriented training with mirror training, as shown in Fig. 1. The task-oriented mirrored upper limb robot reflects the movement trajectory of the patient’s non-affected upper limb to the affected side through sensors. It then drives the affected side to perform bilateral upper limb mirroring movements to promote the recovery of the patient’s upper limb function and activities of daily living.

This study conducted a case-control design to verify the feasibility and safety of this task-oriented mirrored upper limb robot for patients in the subacute phase to provide a more helpful clinical tool for stroke patients.

2 Methods

2.1 Study design

The study design was a prospective, single-blind case-control study in patients with subacute stroke. The researcher who evaluated patients was blind to the grouping. The study was approved by the ethics committee of the rehabilitation hospital affiliated with Fujian University of Traditional Chinese Medicine, and all participants provided written informed consent before enrollment. Our study was registered at China Clinical Trials Register (ChiCTR2200058455).

2.2 Participants

Eligible subacute stroke patients were recruited in the outpatient clinic and wards of the rehabilitation hospital affiliated with Fujian University of Traditional Chinese Medicine between March 2022 and July 2022. The inclusion criteria for this study were: (1) meeting the "Diagnostic criteria of Various Major Cerebrovascular Diseases in China 2019"; (2) duration of disease between 2 weeks and 6 months; (3) age between 18 to 80 years; (4) Brunnstrom stage of the hemiplegic upper limb in stage II–V; (5) upper limb flexor spasticity with the Modified Ashworth Scale score ≤ 2; (6) those who can sit independently. The exclusion criteria were: (1) those who were not out of danger and whose vital signs were still unstable; (2) those with severe lateral neglect impairment; (3) those with severe cardiopulmonary dysfunction; (4) those with complete sensory deficit impairment; (5) those with recent upper limb fracture, severe arthritis, or arthroplasty affecting upper limb function; (6) those who were unable to cooperate with adherence to treatment.
2.3 Intervention

A total of 32 subacute stroke patients were included in this study. The researchers assigned the patients into an experimental or control group based on a paired design in which patients’ age, gender, stroke type, and baseline Fugl-Meyer upper extremity motor score were used as matching criteria. Each group consisted of 16 participants.

Control group

Upper extremity conventional occupational therapy was provided by professional therapists, 5 times a week, 60 minutes each time, for 4 weeks. The conventional occupational therapy was based on the functional performance of the upper limbs and included

1. Upper limb motor function training, including separate and compound movements of the shoulder, elbow, wrist and hand, with particular emphasis on the patient's active movements, such as using rollers and abrasive plates to induce motor control of the patient's upper limbs, encouraging the patient to perform active elbow flexion and extension movements, and performing wrist flexion and wrist extension movements during elbow extension;
2. Fine motor training, focuses on eye-hand coordination, such as when patients can move their fingers on their own, they can use pegs and checkers, and play with play-doh to practice grasping and pinching. They can also choose activities such as paper cutting and playing cards, initially using the affected side of the fixed hand to operate, and then gradually encouraging two-handed operation;
3. Activities of daily living training, according to the performance of the patient's upper limbs, targeted activity analysis and activity design, help patients to carry out individualized daily work therapy so that patients can adapt to daily family life and recreational activities, such as washing, eating, toileting, dressing and undressing with assistance, as well as making their closet and bed.

Experimental group

In addition to the 30-minute conventional rehabilitation therapy which training was the same as the control group, the subjects were given 30-minute task-oriented mirrored training by the professional therapists using the Wisebot X5 upper limb rehabilitation robot, 5 times a week for 4 weeks.

Rehabilitation devices

The Wisebot-X5 is comprised of a 3D exoskeleton robotic system and an integrated virtual-reality somatosensory device, as shown in Fig. 1.

The 3D exoskeleton robotic system (shown as the left device in Fig. 1) includes 3 electric-motor-actuated active DoFs (degrees of freedom) and 2 passive DoFs. The 3 active DoFs assist the patient's shoulder joint for horizontal abduction/adduction (shown as Axis-1 in Fig. 1), flexion/extension (shown as Axis-2 in Fig. 1) and the elbow joint for flexion/extension (shown as Axis-3 in Fig. 1). By controlling the output torque of each motor, the assistance level that the robot provides to the patient can be controlled. The 2
passive DoFs are designed for accommodating the patient’s shoulder internal/external rotation angle (shown as Axis-4 in Fig. 1) and forearm pronation/supination angle (shown as Axis-5 in Fig. 1). To adapt to different body sizes, 4 adjusting modules are designed, the horizontal position of the shoulder can be adjusted via module A in Fig. 1, the height of the shoulder can be adjusted via module B in Fig. 1, the length of the upper-arm can be adjusted via module C in Fig. 1, and the length of the forearm can be adjusted via module D in Fig. 1. To start rehabilitation training, first the left/right configuration of the robot should be changed according to the hemiplegia side of the patient, which can be achieved by one key switch function of Wisebot-X5. Then the patient's arm should be affixed to the exoskeleton via two adjustable cuffs, one for the upper arm (shown as E in Fig. 1) and one for the lower arm (shown as F in Fig. 1). At last, the 4 adjusting modules should be adjusted carefully to accommodate the patient's body size. Besides, the patient's hand should grasp the airbag (shown as G in Fig. 1) during the training process. The airbag could measure the patient's grip force, and promote hand rehabilitation training.

The integrated virtual-reality somatosensory device (shown as the right device in Fig. 1) contains a somatosensory acquisition camera (shown as H in Fig. 1), which can collect the body movements of the participant and project into the virtual-reality environment for real-time interaction. Through visual displays like VR eyes or flat screens (Fig. 1) task-oriented training scenarios can be provided where the participant's actions can be fed back in real-time and an immersive experience can be achieved.

We have designed 30 task-oriented mirrored training for patients in three domains: activities of daily living, work, and entertainment. In the activities of daily living module, we designed scenarios for patients such as tidying up desk, organizing closet, eating, and cooking in the kitchen to create real-life scenarios and corresponding daily living activities movements for patients. In the entertainment module, we designed scenarios such as playing balloons, playing chess, fun planes, animal puzzles, and graph matching to enhance the fun and motivate patients to train. In the work module, we designed scenarios such as glass cleaning and garbage sorting according to patients' needs, to enhance patients' working ability in the corresponding scenarios.

The difficulty of the training increases gradually with the patient's function. The difficulty increases mainly from 2 aspects: motor function and cognitive function. The upper limb robot provides passive, assisted, and active modes for motor function. In the passive mode, the movement speed of the robot arm will increase accordingly with the level of the patient's upper limb movement. In the assisted mode, the higher the difficulty, the less the robot will help the patient. In the active mode, the higher the difficulty level, the greater the robot's resistance to the patient. The cognitive function is mainly reflected in the complexity of the task training. As the patient recovers, the complexity of task training will gradually increase, such as escalating from a one-step instruction task to a two-step instruction task.

The subject sits in a chair while grasping the robot's handle with the affected hand. A large computer screen is used to display the motor tasks and virtual scenarios that the patient needs to perform, while the arm and palm graphics on the screen show the current position of the patient's upper extremity (Fig. 2). An icon or voice instructs the patient's arm to reach the required position to complete the training...
movement. We choose task-oriented mirrored training for the patient, such as putting items into the refrigerator with both hands, catching gold coins with both hands, connecting graphics with both hands, bilateral plus ten calculation scenarios, animal matching scenes, and others. During training, the patient must abduct or forward flex the arm on the unaffected side according to the prompts. The robot collects the movement data of the non-affected upper limb through the body-sensing camera. It reflects it to the affected side through the sensor, thus driving the movement of the upper limb on the affected side and realizing the coordinated movement of the bilateral arm.

2.4 Clinical assessments

Clinical assessment of subacute stroke patients at baseline and after the 4-weeks intervention was completed by an experienced occupational therapist, who was not involved in the training of the upper-limb robotic training.

Primary outcome Measure

Fugl-Meyer Assessment of the Upper Extremity (FMA-UE)

The FMA-UE is used to assess the level of stroke impairment and is widely accepted as a measure of physical impairment after stroke (Fugl-Meyer et al., 1975). The FMA–UE has 33 items assessing shoulder, wrist, hand, and coordination/speed, each rated from 0 to 2, with a total score range of 0 ~ 66, with higher values indicating less upper extremity impairment. The total upper extremity Fugl-Meyer scale score and its four parts were calculated separately to investigate the effects of the upper limb robot on overall upper extremity function and each part.

Secondary Outcome Measures

1. Modified Barthel Index (MBI): The MBI is used to assess the patients’ ability to perform activities of daily living, including 10 items of activities of daily living such as grooming, bathing, eating, toileting, dressing, etc (Mahoney and Barthel, 1965). The total score ranges from 0 to 100; the higher the score, the better the patient’s ability to perform activities of daily living.

2. Stroke Self-Efficacy Scale (SSEQ): The SSEQ is used to measure individual confidence in functional performance after stroke (Jones et al., 2008). It consists of 13 items, each of which is scored on a scale of 0 to 10. The higher the total score of the scale, the higher the self-efficacy of stroke patients in rehabilitation.

3. System Usability Scale (SUS): The SUS is used to examine the usability of the upper limb robot system and consists of 10 questions on perceived usability, with a scale ranging from 0 to 100. A score of 100 indicates complete satisfaction with usability. If a participant gave a score of 70 or higher, the device was considered usable (Bangor et al., 2008).

4. the Chinese version of the Quebec User Evaluation With Assistive Technology (C-QUEST): The C-QUEST is used to examine patients’ satisfaction with the training of the upper limb robotic system (Chan and Chan, 2006). It consists of 12 questions: 8 related to the equipment and 4 related to
the service, rated on a Likert scale from 1 “not at all satisfied” to 5 “very satisfied”. The higher the total score of the scale, the higher the patient’s satisfaction with the equipment.

Among them, the FMA-UE(Fugl-Meyer et al., 1975), MBI(Mahoney and Barthel, 1965), and SSEQ(Jones et al., 2008) were collected at baseline and at the end of the intervention; SUS(Bangor et al., 2008) and QUEST(Chan and Chan, 2006) were collected only after the intervention to assess patient satisfaction with the upper extremity robot.

2.5 Statistical Analysis

Analysis was performed using IBM SPSS Statistics 25.0, and \( P<0.05 \) was considered statistically different. The Shapiro-Wilk test is first used to test the normal distribution of the difference between the two sets of data to be compared. All clinical scores were described as mean \( \pm \) standard deviation if they conformed to normal distribution, or median and quartiles if they did not. To compare the clinical scores (FMA-UE, MBI, and SSEQ) before and after the intervention within each group and the change in clinical scores before and after the intervention between the two groups, paired-sample t-tests were used if they conformed to normal distribution, and Wilcoxon signed rank sum tests were used if they did not.

3 Result

We screened 65 patients, of which 32 met the inclusion criteria and were assigned into two groups based on a case-control principle(Fig. 3). Baseline characteristics are summarized in Table 1. The 2 groups were comparable in terms of age, sex, stroke type and location, and FMA. The 32 participants were, on average, 49 days post-stroke (SD = 35.93). 16 participants were in the control group and 16 were in the experimental group. There were no dropouts in either group.

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Patients information by group</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Experimental group</td>
</tr>
<tr>
<td>Gender</td>
<td>16;11 males/5 females</td>
</tr>
<tr>
<td>Age</td>
<td>58 ( \pm ) 10 years</td>
</tr>
<tr>
<td>Months post-stroke</td>
<td>45 ( \pm ) 31 days</td>
</tr>
<tr>
<td>Type of stroke</td>
<td>8 Hemorragic / 8 Ischemic</td>
</tr>
<tr>
<td>Hemiplegic side(Left side/Right side)</td>
<td>8/8</td>
</tr>
<tr>
<td>FMA-UE Total</td>
<td>19.31 ( \pm ) 17.21</td>
</tr>
<tr>
<td>Modified Barthel Index</td>
<td>47.13 ( \pm ) 17.30</td>
</tr>
</tbody>
</table>
3.1 Primary outcome

Arm/hand function outcomes

In FMA-UE, the scores of the experimental group after the intervention were higher than those before the intervention in terms of the total score, the score of shoulder joint, wrist joint and hand joint activity (P < 0.05). The experimental group was better than the control group in terms of the change score from the baseline to post intervention (P 0.05) (Table 2)(Fig. 4).

**Table 2 Changes in clinical outcome measures. (N=32)**

<table>
<thead>
<tr>
<th>Outcome measure</th>
<th>Group</th>
<th>Pre</th>
<th>Post</th>
<th>p of change within groups</th>
<th>p between groups at baseline</th>
<th>p of changes between groups</th>
</tr>
</thead>
<tbody>
<tr>
<td>FMA-UE Total</td>
<td>Experimental</td>
<td>19.31±17.21</td>
<td>29.68±19.71</td>
<td>&lt;0.001**</td>
<td>0.64</td>
<td>&lt;0.01*</td>
</tr>
<tr>
<td></td>
<td>Control</td>
<td>18.88±18.57</td>
<td>21.81±19.42</td>
<td>&lt;0.01*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>FMA-UE shoulder</td>
<td>Experimental</td>
<td>14.93±10.92</td>
<td>20.37±9.72</td>
<td>&lt;0.001**</td>
<td>0.08</td>
<td>0.07</td>
</tr>
<tr>
<td></td>
<td>Control</td>
<td>12.50±10.00</td>
<td>14.87±9.50</td>
<td>0.02</td>
<td></td>
<td></td>
</tr>
<tr>
<td>FMA-UE wrist</td>
<td>Experimental</td>
<td>1.56±2.37</td>
<td>3.50±3.92</td>
<td>0.01*</td>
<td>0.10</td>
<td>0.07</td>
</tr>
<tr>
<td></td>
<td>Control</td>
<td>1.44±2.78</td>
<td>1.94±3.42</td>
<td>0.11</td>
<td></td>
<td></td>
</tr>
<tr>
<td>FMA-UE hand</td>
<td>Experimental</td>
<td>2.63±3.93</td>
<td>3.25±5.17</td>
<td>&lt;0.01*</td>
<td>0.08</td>
<td>0.05</td>
</tr>
<tr>
<td></td>
<td>Control</td>
<td>2.44±3.79</td>
<td>3.38±4.38</td>
<td>0.24</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MBI Coordination/speed</td>
<td>Experimental</td>
<td>0.19±0.75</td>
<td>0.75±1.34</td>
<td>0.08</td>
<td>0.78</td>
<td>0.06</td>
</tr>
<tr>
<td></td>
<td>Control</td>
<td>0.38±1.50</td>
<td>0.75±1.33</td>
<td>0.16</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MBI</td>
<td>Experimental</td>
<td>47.13±17.30</td>
<td>65.50±16.31</td>
<td>&lt;0.001**</td>
<td>0.16</td>
<td>0.09</td>
</tr>
<tr>
<td></td>
<td>Control</td>
<td>38.13±25.61</td>
<td>48.60±23.86</td>
<td>&lt;0.01*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SSEQ Coordination/speed</td>
<td>Experimental</td>
<td>50.75±10.79</td>
<td>81.68±15.74</td>
<td>&lt;0.001**</td>
<td>0.02</td>
<td>0.36</td>
</tr>
<tr>
<td></td>
<td>Control</td>
<td>52.50±7.54</td>
<td>79.75±7.54</td>
<td>&lt;0.001**</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Results of the paired-samples t-test comparing the baseline and post-intervention FMA-UE, FMA-shoulder, FMA-Wrist, FMA-Hand, FMA-UE Coordination/speed, and MBI scores within the experimental group and the control group. (**p<0.01,*p<0.05)
### 3.2 Secondary outcome

#### Activities of Daily Life outcomes

In activities of daily living, MBI scores of the two groups were significantly improved after the 4-week intervention compared with those before the intervention, with a statistically significant difference ($P < 0.05$) (Table 2). No significant difference was detected between the groups in terms of the change score from the baseline to post intervention ($P > 0.05$) (Table 2)(Figure.4).

#### Stroke self-efficacy questionnaire outcomes

In the rehabilitation self-efficacy of stroke, the SSEQ scores of the two groups were significantly improved after the 4-week intervention compared with those before intervention, with a statistically significant difference ($P < 0.05$) (Table 2). No significant difference was detected between the groups in terms of the change score from the baseline to post intervention ($P > 0.05$) (Table 2)(Figure.3).

#### User satisfaction

Participants were overall satisfied with the device (Table 3). Sixteen participants completed the SUS and C-QUEST questionnaires. The intervention was well-tolerated by the participants, as every participant in the experimental group was able to successfully complete the 30-minutes training. Most reported they enjoyed the training when asked by the study staff. The overall usability of our robot was rated high (74.84 out of 100 on SUS). According to an elaborated analysis of the SUS by Bangor et al.(Bangor et al., 2008), scores above 70 are deemed good and within the range of acceptable devices. We can therefore conclude that with an average score of 74.84, the usability of our robot is sufficient. C-QUEST items were scored at the top of the scale (type Likert from 0 to 5), which is higher than the satisfaction score of the same type of upper limb robot. The satisfaction with the easy installation and adjustment of robots, the
satisfaction with the professional services provided by medical personnel and the safety are the top three items in all the scores.

3.3 Safety

No significant adverse events related to the therapy or the device happened during the clinical research. Several participants commonly reported feeling fatigued following the robotic therapy session, but the robot will adjust the treatment intensity according to the subject's completion of the task.

4 Discussion

We investigated the effects of task-oriented mirrored upper limb robotic training on upper limb motor function, activities of daily living, and self-efficacy of patients with subacute stroke, as well as patients' satisfaction with the upper limb robot. Our results suggest that upper limb training with the upper limb robot is feasible and safe for patients with subacute stroke. There were no serious adverse events during the training process, and after 4-weeks intervention, there were significant improvements in upper limb motor function, activities of daily living, and self-efficacy in the experimental and control groups. The experimental group was significantly better than the control group in terms of upper limb motor function, and the patients had higher self-efficacy and satisfaction with the upper limb robot after training.

A systematic review and meta-analysis including 11 randomized controlled trials involving 493 patients showed that (Chien et al., 2020), robot-assisted therapy produced similar benefits to usual care in the subacute phase of stroke. Chen et al. (Chen et al., 2021) found that exoskeleton robot training that provided task-specific anthropomorphic trajectories and postures to subacute stroke patients helped improve aspects of their upper extremity motor function and activities of daily living. In the present study, task-oriented mirrored upper limb robot training also promoted the improvement of upper limb motor function and activities of daily living.

Studies have shown that, both task-oriented training and mirror training are effective in improving patients' upper extremity motor function and activities of daily living (French et al., 2016a; Thieme et al., 2018; D'Anci et al., 2019). Task-oriented training is based on motor learning theory and allows for repetitive high intensity training for upper body movements and activities of daily living tasks (Veerbeek et al., 2014; French et al., 2016a). Hubbard et al. observed changes in brain activation on functional magnetic resonance imaging in patients who received additional task-specific upper extremity training after stroke, and found increased brain activation in the anterior cingulate area and ipsilateral supplementary motor area and decreased activation in the contralateral cerebellum in patients who received additional task-oriented training compared with standard care (Hubbard et al., 2015b). In addition, in the neuroimaging studies of robot-assisted task-oriented training of the upper extremity, Xie et al. (Xie et al., 2022) used functional near-infrared spectroscopy to observe brain activation during resting or robot-assisted task-directed upper limb motor training in patients with subacute stroke, and found that ipsilateral superior frontal cortex (SFC) activation was significantly increased in patients with muscle strength 4 level or higher, and cortical activation in the bilateral SFC was significantly increased in
patients with muscle strength 2–3 level during upper limb motor training compared with resting state. Thus, robotic task-oriented training improves cortical neuroplasticity in stroke patients and may be important for the recovery of upper limb motor function in patients.

Mirror therapy facilitates the recovery of motor function of the paralyzed limb, by reflecting images from the non-paralyzed side to the paralyzed side(Ramachandran et al., 1995b; Deconinck et al., 2015b; Kim et al., 2022; Heinrich et al., 2022). Meta-analysis showed that mirror therapy had a significant positive effect on motor function and activities of daily living(French et al., 2016b). Madhoun et al. compared task-based mirrored therapy (TBMT) with occupational therapy of equal duration and found that TBMT was significantly better than occupational therapy in FMA-UE and some aspects of the Modified Ashworth Scale (elbow flexion, wrist flexion, wrist extension, finger extension)(Madhoun et al., 2020). Arya et al. found that task-based mirrored therapy also improved flexibility, coordination, and strength in the non-paralyzed upper extremities of patients in the chronic phase of stroke(Arya et al., 2017). Bello et al. reviewed 35 studies enrolling 78 stroke survivors and 396 healthy participants and found that, significant changes in ipsilateral M1 activation after mirror training, with other common sites of activation including primary somatosensory cortex, precuneus and cerebellum(Bello et al., 2020). In addition, it has also been shown that, mirror therapy may affect the excitability of the transcallosal pathway, thereby facilitating communication between the cerebral hemispheres and inducing homeostasis between the motor cortex(Avanzino et al., 2014). The mirror neuron system is also thought to be responsible for the mirror effect, where mirror neurons are activated by motor performance and observation of similar motor activity in mirror images(Carvalho et al., 2013; Abdullahi et al., 2022; Tofani et al., 2022). Activation of these neurons may induce positive cortical reorganization and associated motor control.

Assistive technology helps patients regain good function, work ability or participate in meaningful activities of daily living(Holloway and Dawes, 2016). In the upper limb robotic training, we combined task-oriented training with mirror training to create a rich scenario-based training for patients and increase the fun and purposefulness of training, while task-oriented training provides high-intensity repetitive training based on tasks of daily life activities(French et al., 2016b), strengthening the generalization of upper limb functions in daily life activities, and mirror training can promote ipsilateral primary motor area cortical activation, promote motor cortical reorganization, and promote bilateral upper limb coordinated movements to better promote the recovery of upper limb motor functions(Carvalho et al., 2013; Fritzsch et al., 2014; Selles et al., 2014).

The following limitations of this study exist: first, this study is a case-control design rather than a randomized controlled design, and has a small sample size and a short intervention duration. As a pilot study, this study validated the feasibility and safety of task-oriented mirrored upper limb robotic training in patients with subacute stroke, and the future study could be conducted a randomized controlled trial with a larger sample size to clarify its efficacy on upper limb functional rehabilitation in subacute stroke. Second, this study found that, task-oriented mirrored upper limb robotic training showed a trend of improvement in activities of daily living compared to the control group, but there was no statistical difference. This may be due to the short duration of training, and the improvement in upper limb motor
function of the patients did not translate into improvement in activities of daily living. Therefore, a longer period of longitudinal observation and follow-up may be considered in the next trial to understand the long-term effects. Third, this study failed to conduct a randomized controlled study with a conventional upper limb robot, and it is difficult to respond to whether this task-oriented mirrored upper limb robotic training is superior to other types of upper limb robots, and further comparative studies can be conducted in the future.

5 Conclusion

This study suggested that the use of a task-oriented mirrored upper limb rehabilitation robot for upper limb training in patients with subacute stroke is feasible and safe, and help to promote the recovery of upper limb function, activities of daily living.

Declarations

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Ethics statement

The studies involving human participants were reviewed and approved by the Human Ethics Committee of the rehabilitation hospital affiliated to Fujian University of Traditional Chinese Medicine. The patients/participants provided their written informed consent to participate in this study.

Author contributions

JSW, ZMH and HYD contributed to study design, data collection, drafting and revising the manuscript; YZH and JHW contributed to supervising study design, completing data analysis and interpretation, and revising the manuscript; JH revised the manuscript. All authors have read and approved the final version of the manuscript and agree with the order of the presentation of the authors.

Funding

This research was funded by the Shenzhen Basic Research Program (No. JCYJ20180507182441903), and the Open Research Fund of Fujian Key Laboratory of Rehabilitation Technology (No. KF2019001) and Fujian "Innovation and Entrepreneurship Training Program for College Students".

Conflict of interest

JHW was employed by the Shenzhen Wisemen Medical Technologies Co., Ltd.
The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

References


**Figures**
Figure 1

Components of the Wisebot-X5 robot module A can adjust the horizontal position of shoulder, module B can adjust the height of shoulder, module C can adjust the length of upper-arm, and module D can adjust the length of the forearm. The patient’s arm should be affixed to the exoskeleton via two adjustable cuffs, one for the upper arm (shown as E in Figure 1) and one for the lower arm (shown as F in Figure 1).
Besides, the patient’s hand should grasp the airbag (shown as G in Figure 1) during the training. I represents computer screen and H represents the somatosensory acquisition camera.

Figure 2

(A) subject using the Wisebot-X5 robot; (B) examples of task-oriented mirrored training tasks for patients: (a) organizing closet task; (b) fruit matching task; (c) cooking task; (d) glass cleaning task;
Figure 3

Chart flow of patient recruitment and participation
Figure 4

FMA-UE: Fugl-Meyer Assessment of the Upper Extremity; MBI: Modified Barthel Index; SSEQ: Stroke Self-Efficacy Scale; (**p<0.01; *p<0.01