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Mirror Therapy Using Gesture Recognition for Upper Limb Function, Neck Discomfort, and Quality of Life After Chronic Stroke: A Single-Blind Randomized Controlled Trial

Authors' Contribution:
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Data Collection B
Statistical Analysis C
Data Interpretation D
Manuscript Preparation E
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Background: Mirror therapy for stroke patients was reported to be effective in improving upper-extremity motor function and daily life activity performance. In addition, game-based virtual reality can be realized using a gesture recognition (GR) device, and various tasks can be presented. Therefore, this study investigated changes in upper-extremity motor function, quality of life, and neck discomfort when using a GR device for mirror therapy to observe the upper extremities reflected in the mirror.

Material/Methods: A total of 36 subjects with chronic stroke were randomly divided into 3 groups: GR mirror therapy (n=12), conventional mirror therapy (n=12), and control (n=12) groups. The GR therapy group performed 3D motion input device-based mirror therapy, the conventional mirror therapy group underwent general mirror therapy, and the control group underwent sham therapy. Each group underwent 15 (30 min/d) intervention sessions (3 d/wk for 5 weeks). All subjects were assessed by manual function test, neck discomfort score, and Short-Form 8 in pre- and post-test.

Results: Upper-extremity function, depression, and quality of life in the GR mirror therapy group were significantly better than in the control group. The changes of neck discomfort in the conventional mirror therapy and control groups were significantly greater than in the GR mirror therapy group.

Conclusions: We found that GR device-based mirror therapy is an intervention that improves upper-extremity function, neck discomfort, and quality of life in patients with chronic stroke.

MeSH Keywords: **Quality of Life • Rehabilitation • Stroke**

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Background

In patients with acute stroke that occurred >6 months previously, 85% have upper-limb disorders, and 55% to 75% have upper-limb disorders [1]. The upper-limb movement function is decreased due to weakening of upper-limb muscles, which is primarily caused by changes in the central nervous system and secondarily by weakness due to inactivity and reduced activity [2,3].

Activities of daily living are limited due to body dysfunction, and most stroke patients have limited social interaction; these disorders reduce the quality of life [4–6]. In addition, stroke patients may experience depression due to reduced motivation [6]. Depression results in loss of interest and joy, anxiety, fear, hostility, sadness, and anger, which negatively affect functional recovery and rehabilitation in stroke patients [7].

Constraint-induced movement therapy, action observation training, and mirror therapy have been recently studied as therapies for upper-extremity motor function [8]. These interventions are used to increase the use of paralyzed limbs to overcome disuse syndromes, observe and imitate movement, and change the neural network involved in movement. Providing various tasks in upper-extremity rehabilitation is necessary and virtual reality is used as a method for providing various tasks [9,10].

Interventions using virtual reality require cognitive factors, such as judgment and memory, as the task progresses. It can use visual and auditory stimuli, and can induce interest and motivation, helping stroke patients to be mentally stable and motivated [11]. Gesture recognition (GR) is a topic that studies the reading of these movements using algorithms. These GR algorithms mainly focus on the movement of arm, hands, eyes, legs, and other body parts. The main idea is to capture body movements using capture devices and send the acquired data to a computer [12]. A remarkable example is shown in physical rehabilitation, where the low-cost hardware and algorithms accomplish outstanding results in therapy of patients with mobility issues. A 3D motion input device is required for upper-body rehabilitation in virtual reality. The Leap motion controller, a GR input device, has been recently released, which monitors hand and finger movements and reflects them on the monitor [13]. In addition, game-based virtual reality can be realized using a GR device, and various tasks can be presented.

Mirror therapy has been used as a therapeutic intervention for phantom pain in amputees. The painful and paralyzed body parts are covered with a mirror. The mirror is placed in the center of the body, and the movement of the paralyzed body is viewed through the mirror. The patient has a visual illusion that the paralyzed side is normally moving [14]. Mirror therapy for stroke patients was reported to be effective in upper-extremity motor function and daily life activity performance [15]. However, conventional mirror therapy methods require high concentration and can become tedious, making active participation difficult [16]. In addition, conventional mirror therapy differs from the actual situation wherein a mirror positioned at the center of the body should be viewed with the head sideways. Because patients are in a suboptimal posture, they may have neck discomfort after mirror therapy. The body has muscle strength disproportion when maintaining poor posture for a long time. This results in inadequate tension on adjacent muscles and joints, resulting in movement restriction, reduced flexibility, pain, and changes in bone and soft tissue [17].

This study investigated the effect on upper-extremity motor function, quality of life, and neck discomfort by using GR device mirror therapy in patients with chronic stroke, and evaluated the efficacy of this technique.

Material and Methods

Participants

We studied 36 patients who were diagnosed with hemiplegia due to stroke and were admitted to a hospital in Daejeon, Korea. Power analysis was completed using the G*power program (version 3.1.9.2; Germany). Effect sizes were calculated before subject recruitment using mean and SD from the pilot study that ranged from 0.55 to 0.8. The power was set at 0.8, resulting with a sample size of 12 patients in each group for a 3-group clinical trial. The inclusion criteria of the subjects were as follows: 1) event occurred >6 months previously; 2) sufficient cognition to participate in the training, which was defined as a Mini-Mental State Exam (MMSE) [18] scores of 24 or higher; 3) frequency score of the upper extremity of the motor activity log <2.5, and; 4) no visual impairment and field defect. The exclusion criteria of the subject were as follows: 1) other neurological problems or orthopedic injuries; 2) aphasia that makes intervention difficult; 3) recent participation in other rehabilitation research or drug experiment; and 4) research participation rate <80%.

Clinical procedures

Before the intervention, the subjects were provided sufficient explanation regarding participation in the study, and only the patients who agreed to participate in the study were involved in the intervention. The randomization was performed by selection of an opaque closed envelope wherein the group assignment was written, and the sealed envelope was given to the physical therapist. Thirty-six stroke patients who had been admitted to a rehabilitation clinic in the Republic of Korea were randomized into either the GR mirror therapy group (n=12), the conventional mirror

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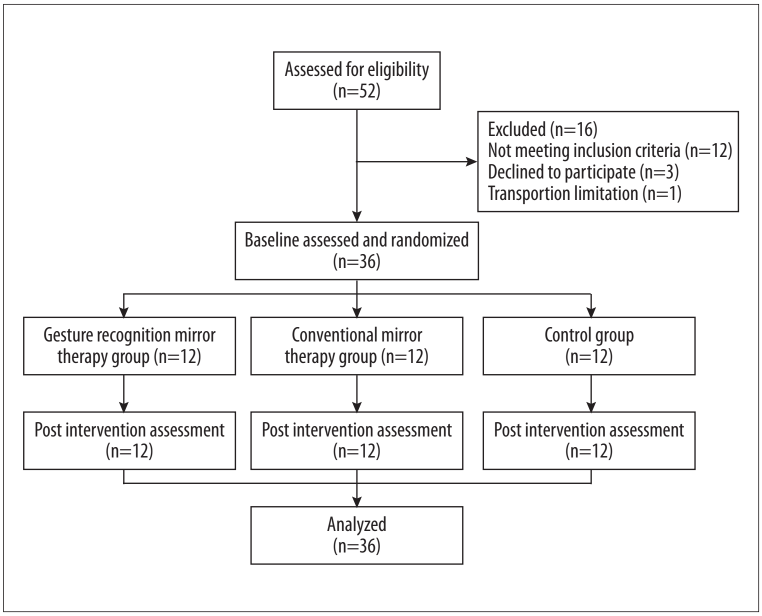

Figure 1. Flowchart of participants through the trial.

therapy group (n=12), or the control group (n=12) group (Figure 1). The experiment began the day after randomization. General surveys of the subjects and pre-intervention tests were conducted. Each participant underwent a training program consisting of 15 sessions, 30 min per day, 3 days per week, for 5 weeks. After 5 weeks, the final assessments were performed. All 3 groups underwent traditional physical therapy, including motor learning and neurodevelopmental treatment.

The GR mirror therapy group used a Leap motion controller (Leap Motion, Inc., USA), a monitor, a mirror, and a Leap Motion App Home. The Leap motion controller is a device with a camera that recognizes the reflected wave of infrared light and detects motion. It can recognize 2 hands and 10 fingers with a 0.01 mm precision and a 200 frames/s speed, and recognizes hand movements by storing the recognized information in the frame unit (Figure 2). There are 6 types of game programs used for intervention: 1. Playground I, 2. Playground II, 3. Playground III, 4. Block Destruction I, 5. Block Destruction II, and 6. Cube Wave. Game programs include actions, such as recognizing a hand, building a block on a moving object, picking up a petal, removing a block, pushing a block by hand, and lifting a hand (Figure 3). The subject sits in a chair without a backrest while looking at the flat mirror in the 45° direction, and the box is covered with the invisible hand. Subsequently, turning the monitor in the 90° direction, the subject can see the mirrored monitor to see the left and right reversed monitor screen. Subjects looked at the left and right screen of the monitor, and moved the right hand on the Leap motion controller to randomly play the game based on the subject's choice. Each game program was performed for approximately 4 min, and the subject rested for approximately 1 min after the game program was finished.

The conventional mirror therapy group underwent training using the general mirror therapy method [19] in which the patient sits on a chair without a backrest and mirror side is placed on the center line of the patient on the table [16]. The affected hand was placed in the mirror box so that the hand could not be seen, and the non-affected hand was placed in front of the mirror side to reflect the shape of the hand on the mirror. The mirror therapy program consists of 10 movements. Three sets of these programs were performed, and 12 operations were performed per set [19]. In the control group, patients underwent sham therapy in the same environment as the mirror therapy group so as not to see the affected hands (Figure 2). All 3 therapy programs included 9 movements: lifting the arms, moving the arms to the left and right, bending and stretching the elbows, raising and lowering the hands, lifting the wrists, lowering the wrists, flexing the wrists inward, flexing the wrist, and finger gripping.

Outcome measurements

The manual function test (MFT) is composed of upper-limb movement (4 items), grasp (2 items), and resin manipulation (2 items) as upper-limb function and motion ability measurement test tool for hemiplegic stroke. The test–retest reliability was 0.99 and 0.84 for the affected and unaffected sides, respectively. The test–retest and inter-test reliability of stroke patients was 0.95, and correlation with recovery Brunnstrom stage was >0.8 [20].

Neck discomfort score (NDS) was used to measure the degree of subjective neck discomfort. The score rating scale is clearly rated numerically as compared to the Visual Analog Scale. The 10-cm horizontal line was divided by 1 cm intervals, wherein

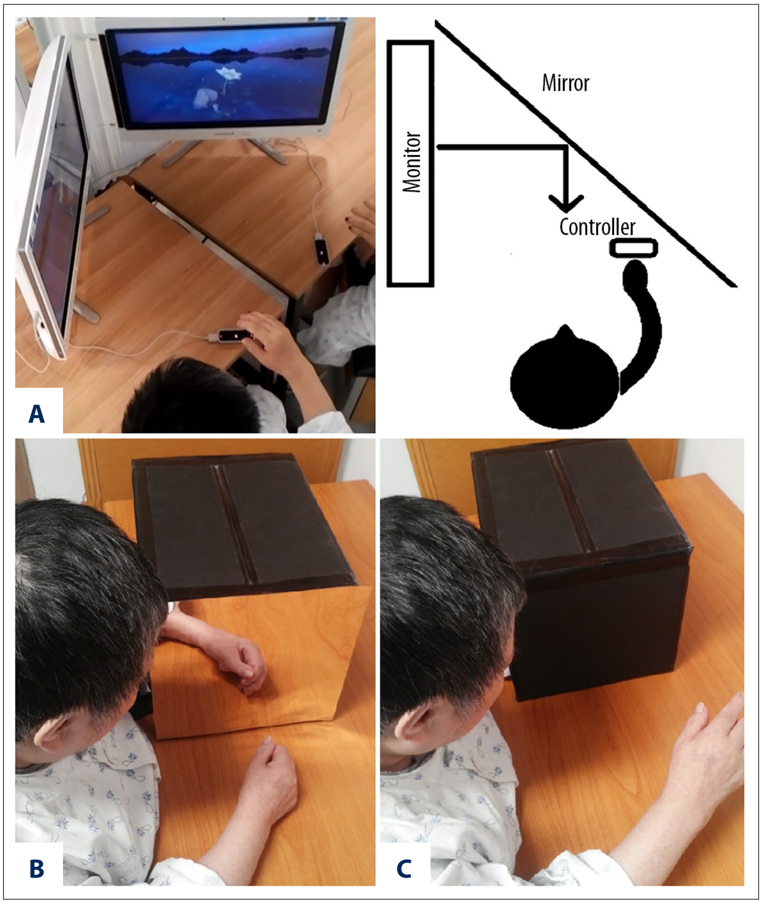

Figure 2. (**A**) Gesture recognition mirror therapy group, (**B**) Conventional mirror therapy, (**C**) Control group.

0 cm level means uncomfortable feeling with no discomfort. We asked the subjects to rate their neck discomfort. The neck discomfort change was measured pre-intervention, post-intervention, and after a 30-min rest.

Short-Form 8 (SF-8) was used to assess life satisfaction with health, which can be answered within 10 min with a reliable test tool, can be evaluated at all ages, and is not affected by cultural differences. It is a comprehensive health-related quality of life instrument that measures the 8 major areas of life satisfaction: overall health status, physical functioning, physical role limitation, pain, vitality, social functioning, mental health, and emotional role restriction. It is a simple questionnaire, in which a higher score shows better function. The reliability Cronbach's α of the SF-8 was 0.82 [21,22].

Statistical methods

For this study, the PASW Statistics ver. 18.0 program (IBM Co., Armonk, NY, USA) was used for data analysis. The general characteristics of subjects were described using the mean and standard deviation values, and the Shapiro–Wilk test was performed to verify the normality of the subjects. The paired *t* test was used to compare between 2 groups before and after intervention, and one-way ANOVA was used to compare differences in the amount of change between each group. The Scheffe method was used for as a post hoc test when differences were found between groups. The significance level was set at α=0.05.

Ethical considerations

This study was conducted with the approval of the Institutional Review Board of Daejeon University (1040647-201606-HR-032-03).

Results

No significant differences were found for gender, age, height, weight, onset type, paralysis, duration of illness, or perception among the 3 groups ($p>0.05$). The general characteristics of the study subjects are shown in Table 1.

The scores of the upper-extremity exercise functions before the intervention were homogeneous in the 3 groups (Table 2). After the 5-week intervention, all 3 groups showed statistically significant increases in upper-extremity motor function ($p<0.05$).

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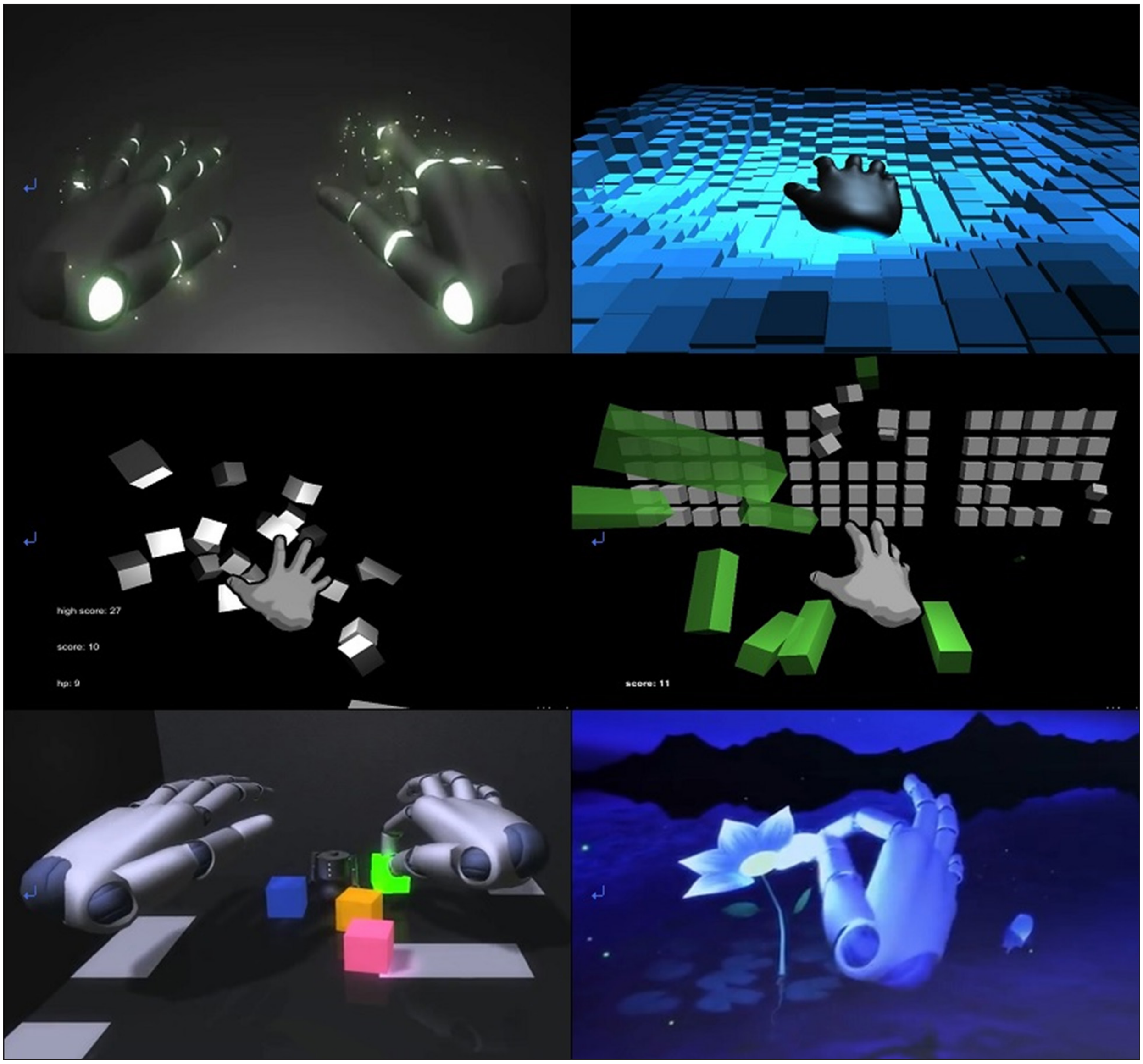

Figure 3. Game programs for gesture recognition mirror therapy.

The difference between the GR mirror therapy group versus the conventional mirror therapy and control groups was statistically significant ($p<0.05$) ($F=16.612$, $p<0.05$).

The scores on the pre-intervention prevalence of neck discomfort were the same in the 3 groups (Table 2). Changes in neck discomfort among the 3 groups were as follows ($F=32.501$, $p<0.05$): no statistically significant difference was found in the GR mirror therapy group ($F=1.709$, $p>0.05$); the difference in neck discomfort between the conventional mirror therapy and control groups was higher than that in the conventional mirror therapy group, but was not significant ($p>0.05$); and no difference was found between the 3 groups after a 30-min rest ($F=0.094$, $p>0.05$).

The changes in quality of life among the 3 groups after 5 weeks of intervention are shown I Table 2. A statistically significant increase was found in the quality of life after intervention in the conventional mirror therapy and GR mirror therapy groups ($p<0.05$). The difference between the 3 groups was significantly higher in the GR mirror therapy group than in the control group ($F=3.673$, $p<0.05$).

Discussion

This study investigated changes in upper-extremity motor function, quality of life, and neck discomfort when using a GR device for mirror therapy to observe the upper extremities reflected in the mirror. The 5-week intervention confirmed the

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Table 1. General characteristics of subjects.

Characteristic	Gesture recognition mirror therapy group (n=12)	Conventional mirror therapy group (n=12)	Control group (n=12)	χ^2/F
Gender (Male/Female)	7/5	7/5	9/3	0.963
Age (y)	58.00±15.15	59.58±11.87	59.33±13.63	0.047
Height (cm)	168.89±10.09	165.78±10.23	166.56±3.40	0.598
Weight (kg)	61.66±11.85	60.82±10.93	66.00±14.55	0.588
Paretic side (right/left)	4/8	5/7	5/7	0.234
Symptom onset (month)	28.91±15.80	26.33±15.51	29.00±19.21	0.096
MMSE (score)	26.92±2.15	26.50±2.32	26.50±2.11	0.147

Values are presented as number only or mean ±SD. MMSE – mini–mental state examination.

Table 2. Outcome measurements pre-post intervention comparison of three groups.

Variables	Gesture recognition mirror therapy (n=12)	Conventional mirror therapy group (n=12)	Control group (n=12)	F	Post-hoc
Manual function test					
Pre	8.92±2.54	9.50±2.15	9.00±1.95	0.240	
Post	13.42±2.50	12.33±2.02	10.08±1.93	7.410	
t	9.950*	5.977*	3.463*		
Change	4.50±1.57$^{\#,\#\#}$	2.83±1.64$^{\#}$	1.08±1.08	16.612*	A>B>C
Neck discomfort score					
Pre	1.65±0.68	1.50±0.67	1.73±0.42	0.462	A=B=C
Post	2.07±0.45$^{\#,\#\#}$	3.72±0.46	3.28±0.50	32.501*	A<B,C
Rest	1.83±0.51	1.82±0.54	1.75±0.54	0.094	A=B=C
F	1.709	76.161*	39.649*		
Short form 8					
Pre	38.23±9.96	39.00±13.56	37.39±6.17	0.072	
Post	42.60±8.67	42.00±11.68	37.45±6.62	1.121	
t	4.192*	2.460*	0.044		
Change	4.37±3.61$^{\#}$	2.92±4.23$^{\#}$	0.05±4.27	3.673*	A,B>C

Values are presented as mean ±SD. $^{\#}$ Significant difference compared with the control group (p<0.05); $^{\#\#}$ Significant difference compared with the conventional mirror therapy group (p<0.05); * p<0.05.

positive effect of upper-limb movement function and quality of life in patients with chronic stroke.

The MFT was used to measure upper-extremity motor function. After the intervention, the GR mirror therapy, conventional mirror therapy, and control groups were significantly improved. The amount of change after intervention was significantly greater in the GR mirror therapy group than in the conventional mirror therapy and control groups. Significant improvement in the upper-limb movement function was also observed in the mirror therapy group, as the effect of the mirror therapy and the intervention program of the 3D motion input unit provided tasks and feedback to the subject. The control group also showed a significant increase in upper-limb movement

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function after the intervention, but this is thought to be due to the movement of the subject using the target action of the proximal part in performing the sham therapy. In addition, the difference between the conventional mirror therapy group and the control group was significant because the visual stimulation through the mirror therapy had a positive effect on upper-limb movement function [23]. The upper-limb movement function was improved by mirror therapy, whereas the mirror therapy showed passive observation of movements and imitation of behavior and stimulation of cerebral cortex and spinal area. Previous studies also showed improvement of upper-limb movement through mirror therapy. The GR mirror therapy group showed significantly more improvement than the conventional mirror therapy and control groups. GR mirror therapy has many more movement processes using the wrist and hand than in the conventional mirror therapy. In addition, the conventional mirror therapy program was more biased toward the motion than the speed and accuracy of the motion. However, the GR mirror therapy group is required because of the accuracy and speed to perform tasks in program configuration [19]. A previous study reported an improvement in coordination, dexterity, hand use ability, and grasp force using a Leap motion controller with stroke patients [12,24].

No statistically significant difference was found in the change of NDS between the conventional mirror therapy and control groups, but no difference was observed between the 3 groups after 30-min rest. This is because, unlike the GR mirror therapy group with the mirror on the front, the conventional mirror therapy and control groups are thought to have increased neck discomfort because the box located on the affected side should be turned to the side of the head [25]. The subjects were more interested in their therapy than were other patients because of the electronic devices used in the virtual reality game program, and they enjoyed playing the game program, which had a positive psychological effect. After the intervention, a significant increase was found in the conventional and control groups. In the GR mirror therapy group, was no difference was found.

As a result of measuring the quality of life using SF-8, a significant improvement was found in the conventional mirror therapy and GR mirror therapy groups after the intervention, and the change before and after the intervention showed that the GR mirror therapy group was comparable with the control group. This is because the motivation and rehabilitation intention of the subjects were improved due to the virtual reality game program and the mirror therapy; the subjects played the game program in virtual reality, which had a positive influence due to voluntary intervention participation [26,27]. Use of virtual reality in stroke patients has been found to improve quality of life, performance, satisfaction, motivation, and interest. Quality of life was shown to be improved by applying a virtual reality-based exercise program to children with brain damage [27].

The clinical significance of this study is that it can be clinically applied to improve upper-limb movement function in stroke patients in clinical practice. The virtual reality game program and the preparation of the mirror therapy are simple, and the cost is low because expensive equipment is not needed [13]. In addition, it can encourage voluntary participation of the subjects by inducing interest in the virtual reality game program, and can be used by people with severe paralysis. In addition, because mirror therapy is performed while looking at the front, conventional mirror therapy produces less neck discomfort.

The limitations of this study are as follows. First, generalizing the results is difficult because the number of subjects was small. Future studies will need to involve more participants. Second, expecting the same results for acute and subacute patients is difficult because the study was conducted on patients who had chronic stroke. Third, because it was intended for hospitalized patients, it would have reflected the effects of basic hospitalization and medication, which should be compensated for, and absence of follow-up after the end of intervention did not allow for determination of the durability of effects. Future studies should investigate the effect of mirror therapy using various devices, and more effective mirror therapy program are needed.

Conclusions

The results of this study suggest that mirror therapy with a GR device has a positive effect on upper-extremity motor function and quality of life of patients with chronic stroke. Mirror therapy was found to produce less neck discomfort. Future studies on upper-extremity exercise function, quality of life, depression, and neck discomfort stroke patients are necessary.

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