Neurology Asia 2020; 25(3) : 245 – 251

Improving upper extremity motor function in stroke patients using a complex task with multi-joint-based mirror therapy: A randomized controlled trial

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Abstract

Background & Objective: Mirror therapy has been shown to be effective in restoring upper extremity function in stroke patients through changes in the central nervous system. Therefore, it is important to evaluate the effectiveness of various tasks to induce central nervous system excitation. This study investigated the effect of using a complex task with multi-joint-based mirror therapy on upper extremity function and activities of daily living (ADL) in patients with hemiplegia after a stroke. Methods: In this study, 25 stroke patients were recruited and assigned randomly to the experimental or control group. The experimental group received a complex task using multi-joint-based mirror therapy, and the control group received a simple task using single-joint-based mirror therapy. Both groups received the same standard rehabilitation treatment 5 days per week for 4 weeks. An upper extremity evaluation was performed using the Fugl-Meyer Assessment (FMA) and Motor Activity log (MAL). The FMA includes an upper extremity subsection (FMA-UE) as well as upper arm (FMA-UA) and wrist/hand (FMA-WH) subparts. The MAL includes quality of movement (QOM) and amount of use (AOU) subsections. ADL were evaluated using the Korean version of the Modified Barthel Index (K-MBI). Results: Compared with the control group, the experimental group showed greater improvement on the FMA-UE, -UA, and -WH ($p = 0.034$, 0.047, and 0.013, respectively); MAL-AOU and -QOM ($p = 0.048$ and 0.034, respectively); and K-MBI ($p = 0.031$). The following effect sizes (Cohen's d) were observed: FMA-UE, -UA, and -WH (1.0); MAL-AOU (0.2); MAL-QOM (1.6); and K-MBI (0.2).
Conclusions: This study demonstrates that a complex task using multi-joint-based mirror therapy is more effective in restoring upper limb function and ADL in stroke patients than simple task-based mirror therapy.

Keywords: mirror therapy, stroke, complex task

INTRODUCTION

Upper extremity (UE) paralysis is a common problem after stroke. UE paralysis reduces function in activities such as reaching, grasping, and manipulation, resulting in negative effects on activities of daily living (ADL) and quality of life.[1] Therefore, treatment that facilitates UE recovery is important for stroke patients.

Mirror therapy is used in clinical practice for the recovery of motor function in stroke patients. The goal of mirror therapy is to provide visual feedback about movement of the affected limb, which is generated through the mirror reflection of movement by the unaffected limb. Neurophysiologically, mirror therapy facilitates motor learning and induces cortical reorganization associated with positive motor recovery.[2,3] Thus, the effectiveness of mirror therapy depends on brain plasticity.

Mirror therapy has been well documented over the last few years and has proven its effectiveness. However, there is little difference in the method of applying mirror therapy. In other words, the method of mirror therapy varies slightly depending

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Date of submission: 27 March 2020, Date of acceptance: 26 May 2020

on the level of activity of the paralyzed upper limb reflected in the mirror. Previous studies have shown that simple motion such as wrist and finger movements have been attempted in mirror therapy and as a result have had a positive effect on upper limb function recovery.[4,5]

Recently, several studies have reported the results of task-based mirror therapy.[6-8] These studies found that task-based mirror therapy was more effective in restoring the function of the affected limb via excitation of the central nervous system (CNS) than was a simple movement or task. The underlying mechanism of these effects is considered to be CNS activation, the degree of which is related to the size and complexity of the activity performed.[9,10] In addition, because use of the upper limb in daily life entails coordinated movement of multi joints rather than a few independent joints, to achieve optimal outcomes it is important to perform complex tasks using multi-joint-based mirror therapy. However, previous studies have mostly demonstrated the effectiveness of mirror therapy based on relatively simple tasks using the hand or wrist (e.g., faucet rotation, cupping, and moving wood chips). Therefore, this study investigated the effects of multi-joint-based mirror therapy using a complex task. The hypothesis of this study is that the experimental group performing the multi-joint-based mirror therapy using a complex task will show a significant improvement in the upper limb function and daily life than the control group performing the simple task using single-joint-based mirror therapy.

METHODS

Stroke patients were recruited from the rehabilitation center of a local university hospital from October 2017 to February 2018. Participants were assigned by an occupational therapist to the experimental group (n = 13) or control group (n = 12) by blocked randomization to ensure equal numbers in both groups. The allocation sequence was generated via a Web-based random allocation system.

The inclusion criteria were as follows: (1) first stroke with a right or left hemisphere lesion; (2) time since stroke onset <6 months; (3) no significant cognitive problems (Mini-Mental Status Examination-Korean version score >24; (4) ability to imagine (an average score <3 on the vividness of Movement Imagery Questionnaire); (5) manual UE muscle testing minimal grade >fair; and (6) Modified Ashworth Scale score <2. The exclusion criteria were: (1) visual impairments (visual acuity or field) that might limit participation in mirror therapy; (2) visuospatial neglect; (3) communication problems such as aphasia or apraxia; (4) pain, inflammation, or swelling in the affected arm; (5) mental illness; and (6) musculoskeletal disease. We explained the objectives and requirements of our study to all participants, and they voluntarily signed informed consent forms. Ethical approval was obtained from the Inje University Institutional Review Board prior to the experiment (2018-05-067-002).

Procedures

This study performed two group, pre-post design. The experimental group performed a complex task using multi-joint-based mirror therapy for the affected upper limb. The multi-joint-based mirror therapy applied in this study was defined as the simultaneous use of at least three joints on the paralyzed upper limb.

We designed a large-sized mirror (height 40", width 32") for this purpose. Participants sat in a chair with both arms resting on a desk. The mirror described above was placed between their arms so that the paralyzed upper limb was reflected in the mirror. Participants observed the unaffected UE, which was also reflected in the mirror. Thus, the image of the unaffected UE was projected over the affected limb, creating a perception of bilateral movement. The task was developed based on previous studies and was configured to be performed using the shoulder, elbow, wrist, and fingers[6,8] (Table 1). For this study, five complex tasks with similar difficulty were developed. Subjects randomly selected two or three of the five complex tasks and performed them for 30 min.

By contrast, the control group performed mirror therapy focusing on a single joint. Except for the size of the mirror (height 16", width 32") and the type of task, the process was the same as for the experimental group. The tasks, which were simple and used a single joint, were selected with reference to previous studies[6,8] (Table 1). In both groups, mirror therapy was performed for 4 weeks, five times per week, for 30 min per day. After mirror therapy, both groups received traditional rehabilitation, including manual therapy, self-exercise, and sensory stimulation. The subjects' characteristics and all outcome measures were assessed before and after (4 weeks) the intervention by an experienced occupational therapist. The assessment was not blind due to lack of manpower.

Table 1: Complex tasks and simple tasks

	Task	Target movement
Experimental Group	- Cleaning table and window using a duster	- Shoulder flexion, extension, adduction, circumduction Elbow flexion, extension Wrist deviation
	- Picking up clips, beads, coins, and cereals from high or far away	- Shoulder flexion, extension, protraction, retraction Elbow flexion, extension Wrist flexion, extension
	- In-hand manipulation and throwing (Put the coins in the basket after the palm to finger, finger to palm)	- Elbow flexion, extension Wrist flexion, extension Finger pinch, flexion, extension
	- Actively play instruments (e.g., drums and piano)	- Shoulder flexion, extension, Elbow flexion, extension Wrist deviation, Hand grasp
	- Actively doing exercises or copy (e.g., boxing and badminton)	- Shoulder flexion, extension Elbow flexion, extension Hand grasp
Control Group	- Pick up a coin or bean	- Elbow flexion, Wrist flexion, extension Finger pinch
	- Flip a card	- Forearm supination Finger pinch
	- Put block into bucket	- Elbow flexion, extension Finger pinch
	- Stacking cone	- Elbow flexion, extension Hand grasp
	- Flipping book pages	- Wrist flexion, extension

Outcome measures

The primary outcome measurement in this study is the Fugl-Meyer Assessment (FMA) and the Motor Activity Log (MAL). The highest score on the UE subsection of the FMA (FMA-UE) is 66, with subscores of 36 for the upper arm (FMA-UA) and 30 for the wrist and hand (FMA-WH) subsections. Each item is graded on a 3-point ordinal scale. Scoring is based on the direct observation of movement performance by the patient. The FMA-UE exhibited high reliability (r = 0.98–0.99) and validity (r = 0.61–0.94) for assessing the upper extremity motor recovery in poststroke patients.[11,12]

The MAL is a semi-structured interview used to evaluate the quality of movement (QOM) and amount of use (AOU) of the affected arm. It is composed of 30 items related to ADL, with each activity scored on a 6-point scale (0 = never: the affected arm is not used at all; 5 = normal: the ability to use the affected arm is as good as before the stroke).[13] The internal consistency was Cronbach's α=.81-.87, and the test-retest reliability was high.[14]

The secondary outcome measurement in this study is the Korean version of the modified Barthel Index (K-MBI). The K-MBI was used to evaluate ADL and the degree of independence through observation and interviews. The K-MBI is a revision of the original Modified Barthel Index (MBI), intended to make it appropriate for the Korean culture. This assessment consists of 10 subtests in ADL domains (feeding, dressing, grooming, bathing, transfer, toilet use, mobility, stairs, and bowel/bladder). Items are scored on a

5-point scale based on the amount of assistance needed. Scores are summed to give a total score, which ranges from 0 to 100 (0: total dependence; 100: total independence). In this study, self-care subtests related to upper limb functions such as eating, grooming, dressing, bathing, and toileting were analyzed separately.[15] The K-MBI demonstrated good inter-rater reliabilities (r = 0.93 ~ 0.98) and internal consistency (Cronbach's alpha = 0.84). In construct validation, each item of the K-MBI had significant correlation with the total score of K-MBI (r = 0.54 ~ 0.78).[16]

Data analysis

Participant characteristics were analyzed using a statistical software program (SPSS Statistics 20). Descriptive statistics are presented as means with standard deviations. The Wilcoxon signed-rank test was used to compare the outcome measures before and after intervention. The Mann-Whitney U test was used to compare pre- and post-intervention data between groups. The significance level was set at $p < 0.05$. In addition, the effect size (Cohen's d) was calculated by dividing the standardized mean difference between the two groups by the pooled standard deviation. Effect sizes of 0.2, 0.5, and 0.8 represent small, moderate, and large effects, respectively.

RESULTS

Of the original 25 subjects, 4 (2 from the experimental group and 2 from the control group) dropped out before the post-test due to discharge or transfer to another hospital. Therefore, this study analyzed the data of 21 patients (11 in the experimental group and 10 in the control group). There were no significant differences between the groups in any variable at baseline ($p > 0.05$). Table 2 shows the participants' characteristics. Figure 1 shows the CONSORT diagram of participant recruitment.

FMA assessment

Both groups showed statistically significant improvement in FMA-UE, -UA, and -WH ($p < 0.05$). After the intervention, the patients in the experimental group showed greater improvement in the FMA-UE, -UA, and -WH ($p = 0.034, 0.047$, and 0.013, respectively) than did the control group (Table 3). In a comparison of the amount of change in the groups, both groups showed significant differences in FMA-UE, -UA, and -WH ($p = 0.016$, 0.014 and 0.004, respectively) (Table 4). The effect sizes observed for the FMA-UE, -UA, and -WH were 1.0, 0.3, and 0.2, respectively.

MAL assessment

Both groups showed statistically significant improvement in the MAL-AOU and -QOM ($p < 0.05$). After the intervention, patients in the experimental group showed greater improvement in the MAL-AOU and -QOM ($p = 0.048$ and 0.034, respectively) than did those in the control group (Table 3). In a comparison of the amount of change in the groups, both groups showed significant differences in MAL-AOU and -QOM ($p = 0.021$ and 0.004) (Table 4). The effect sizes observed for the MAL-AOU and -QOM were 1.0 and 0.3, respectively.

ADL assessment

Both groups showed statistically significant improvement in their K-MBI scores ($p < 0.05$). After the intervention, those in the experimental group showed greater improvement in the K-MBI ($p = 0.031$) compared with the control group (Table 3). In a comparison of the amount of change in the groups, both groups showed significant differences in K-MBI ($p = 0.046$) (Table 4). The effect size for the K-MBI was 1.0

Table 2: Characteristics of participants

Characteristics	Experimental Group (n=11)	Control group (n=10)
Age(year), mean ± SD	50.91±8.73	48.30±10.22
Gender (male/female)	3/8	4/6
Type of stroke (Hemorrhage/Infarction)	3/8	4/6
Side of stroke (Right/Left)	7/4	6/4
Time since onset of stroke months, mean ± SD	2.91±1.57	3.30±1.76

SD: standard deviation

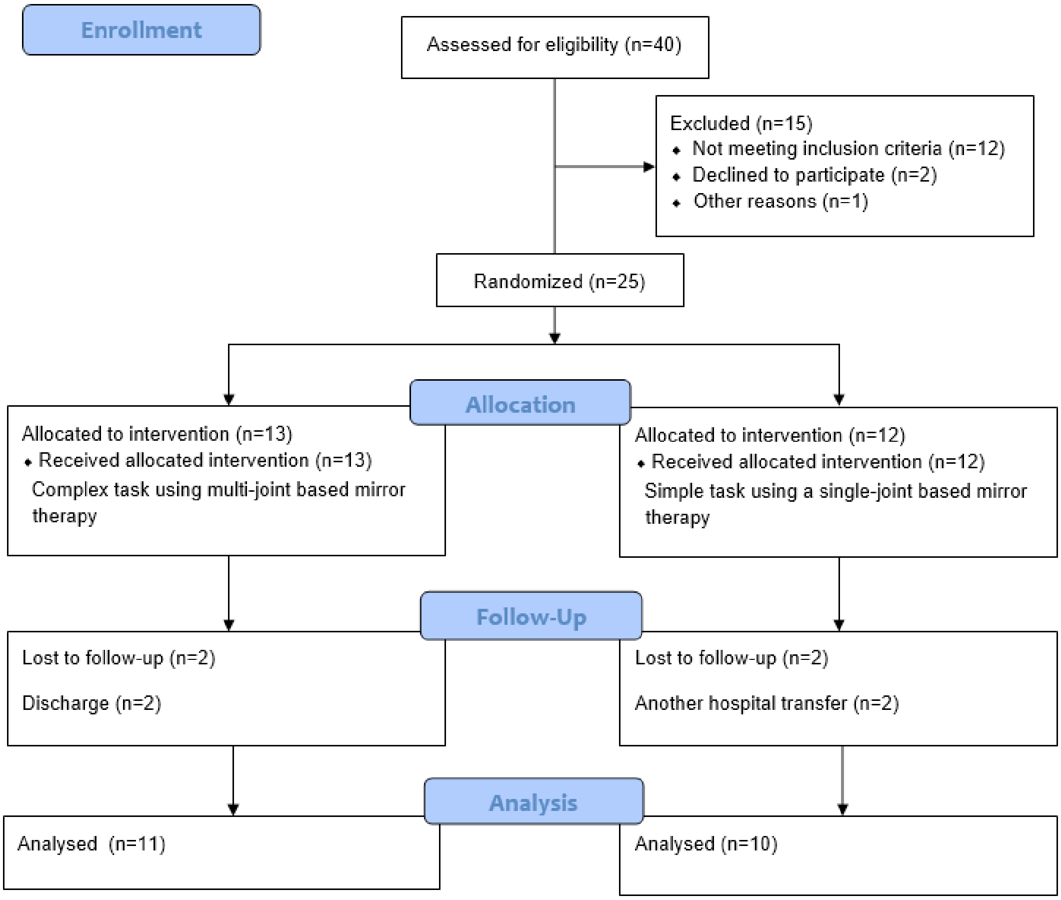

Figure 1. The process of recruitment

DISCUSSION

Previous studies related to mirror therapy have reported relatively simple and tasks using two or less joints. But, ADL using upper limb require complex and rhythmic movements using multi-joint rather than simple movement. Therefore, a relatively simple, multi-joint mirror therapy than mirror therapy using single joint motion can be useful for restoring upper extremity function and activities of daily living. This study investigated the effects of multi-joint-based mirror therapy using a complex task on upper limb function in hemiplegic patients after a stroke. The results show

Table 3: Comparison of results between experimental group and control group

	Experimental group			Control Group			Between groups *P-values*
	Before treatment	After treatment	*p*-value	Before treatment	After treatment	*p*-value	
FMAUA	18.64(7.96)	21.45(8.59)	.004**	13.30(7.28)	14.30(7.15)	.046*	.047†
FMAWH	3.27(4.24)	4.91(4.36)	.007**	1.30(1.70)	1.70(1.76)	.046*	.013†
FMAUE	21.91(10.86)	26.36(11.75)	.003**	14.60(8.90)	16.00(8.70)	.030*	.034†
MALAOU	10.64(7.29)	17.64(7.28)	.005**	9.50(4.67)	11.40(6.00)	.017*	.048†
MALQOM	14.91(9.70)	20.91(12.80)	.005**	10.80(5.77)	12.00(6.20)	.034*	.034†
MBI	23.73(7.70)	26.55(5.71)	.007**	18.80(7.22)	19.40(7.18)	.034*	.031†

The values are mean ± standard deviation, *p<0.05, **p < 0.01 by Mann Whitney test, †p < 0.05 Wilcoxon signed rank test.

Table 4: Comparison of the differences after the 4-week treatment in the two groups

	Experimental group	Control group	*p*-value
FMAUA	2.81(2.35)	1.00(1.15)	.016†
FMAWH	1.63(1.43)	0.40(0.51)	.014†
FMAUE	4.45(3.01)	1.40(1.42)	.004†
MALAOU	7.00(6.29)	1.90(2.02)	.021†
MALQOM	6.00(6.94)	1.20(2.44)	.004†
MBI	2.81(4.53)	0.60(0.67)	.046†

The values are mean ± standard deviation, †$p < 0.05$ Wilcoxon signed rank test.

that using a complex task with multi-joint-based mirror therapy was more effective for improving upper limb function and ADL than was using a simple task and single-joint-based mirror therapy.

Stroke patient recovery through mirror therapy is explained by neurological changes based on brain plasticity.[17,18] First, mirror therapy is directly related to the activation of mirror neurons in the brain.[19] In stroke patients, these mirror neurons respond more strongly when performing specific tasks during mirror therapy than when not engaged in task performance.[20] When the patient observes a motor task in a mirror, these neurons fire, ultimately facilitating mastery of new motor skills through vasomotor–proprioceptive input.[6] Also, mirror therapy is known to activate motor-related areas of the brain in stroke patients.[19] The activated premotor area replaces the primary motor area, which lost function after the brain injury, resulting in the recovery of motor function on the affected side.[20,21] In other words, mirror therapy primarily affects CNS-level changes and secondarily has positive effects at structural levels involved in body movements. Previous studies have shown that mirror therapy is an effective method for improving upper limb function in stroke patients, similar to the results of this study.[8,22]

The most important factor in successful rehabilitation through mirror therapy is activation of the CNS by aggressive activation of motor-related brain areas. Mirror therapy facilitates brain reorganization through activation of the CNS.[23] In particular, these changes in the CNS are known to depend on imagined force levels or task complexity. Previous studies have shown that the greater the imagined force level and task complexity are, the greater the corticospinal excitation will be.[9,10] Therefore, the larger the image size and range of motion reflected in the mirror during mirror therapy are, and the more complex the task is, the greater the corticospinal excitation. This facilitation of neurological changes could lead to recovery of function in conditions like stroke.

Recently, several studies have reported that task-based mirror therapy is more effective than simple movement of the affected upper limb, even when it is reflected in the mirror. This is explained by the effect of interlimb transfer.[8] Yoo *et al.* reported that participants performing a functional task during mirror therapy reported more effective interlimb transfer than did the group performing simple motions.[24,25] This suggests that task-based mirror therapy using a complex functional task, rather than simple movement-based mirror therapy, is more effective in restoring motor function on the affected side through interlimb transfer. This supports the results of the present study.

Most of the upper limb movements required for ADL involve complex rhythmic movements of multiple joints rather than simple movements of single joints. For example, daily tasks such as hair brushing, eating, and bathing require coordinated movement of a multi-joint complex of the shoulder, elbow, wrist, and hand. Therefore, in this study, unlike in previous studies, mirror therapy using complex tasks that required large motions using upper-extremity multi-joint systems was applied. As a result, the use frequency of the paralyzed upper limb improved in the MAL assessment, and the ADL improved significantly compared with the control group, who used a simple task. Patients with hemiplegia after a stroke often have a tendency to learn non-use of the paralyzed upper limb, sometimes referred to as the unuse phenomenon.[23] As a result, the use frequency of the affected upper limb is reduced, which has additional negative effects in that only the unaffected side is used in daily life. Therefore, it is important to improve awareness of the whole upper limb on the affected side through sustained active movement of that side.

This study has some limitations. First, it is difficult to generalize the results of this study because the sample was small. Second, we did not identify changes in the CNS because we did not measure actual brain activation. Third, the long-term effects of this intervention are unknown.

In conclusion, this study suggests that a complex, multi-joint task for the paralyzed limb may have a more positive effect on improving awareness of the limb and improving the frequency of its use in daily life than does a simple task requiring small movements.

DISCLOSURE

Financial support: This work was supported by the 2019 Inje University research grant.

Conflict of interest: None.

REFERENCES

1. Nichols-Larsen DS, Clark PC, Zeringue A, Greenspan A, Blanton S. Factors influencing stroke survivors' quality of life during subacute recovery. *Stroke* 2005; 36:1480-4.
2. Carvalho D, Teixeira S, Lucas M, et al. The mirror neuron system in post-stroke rehabilitation. *Int Arch Med* 2013; 6:41-7682-6-41.
3. Selles RW, Michielsen ME, Bussmann JB, *et al*. Effects of a mirror-induced visual illusion on a reaching task in stroke patients: implications for mirror therapy training. *Neurorehabil Neural Repair* 2014; 28:652-9.
4. Oujamaa L, Relave I, Froger J, Mottet D, Pelissier JY. Rehabilitation of arm function after stroke. Literature review. *Ann Phys Rehabil Med* 2009; 52:269-93.
5. Yavuzer G, Selles R, Sezer N, *et al*. Mirror therapy improves hand function in subacute stroke: a randomized controlled trial. *Arch Phys Med Rehabil* 2008; 89:393-8.
6. Arya KN, Pandian S, Kumar D, Puri V. Task-Based Mirror Therapy Augmenting Motor Recovery in Poststroke Hemiparesis: A Randomized Controlled Trial. *J Stroke Cerebrovasc Dis* 2015; 24:1738-48.
7. Arya KN, Pandian S, Kumar D. Task-based mirror therapy enhances ipsilesional motor functions in stroke: A pilot study. *J Bodyw Mov Ther* 2017; 21:334-41.
8. Lim KB, Lee HJ, Yoo J, Yun HJ, Hwang HJ. Efficacy of Mirror Therapy Containing Functional Tasks in Poststroke Patients. *Ann Rehabil Med* 2016; 40:629-36.
9. Mizuguchi N, Umehara I, Nakata H, Kanosue K. Modulation of corticospinal excitability dependent upon imagined force level. *Exp Brain Res* 2013; 230:243-9.
10. Roosink M, Zijdewind I. Corticospinal excitability during observation and imagery of simple and complex hand tasks: implications for motor rehabilitation. *Behav Brain Res* 2010; 213:35-41.
11. Sanford J, Moreland J, Swanson LR, Stratford PW, Gowland C. Reliability of the Fugl-Meyer assessment for testing motor performance in patients following stroke. *Phys Ther* 1993; 73:447-54.
12. Duncan PW, Propst M, Nelson SG. Reliability of the Fugl-Meyer assessment of sensorimotor recovery following cerebrovascular accident. *Phys Ther* 1983; 63:1606-10.
13. Hammer AM, Lindmark B. Responsiveness and validity of the Motor Activity Log in patients during the subacute phase after stroke. *Disabil Rehabil* 2010; 32:1184-93.
14. Uswatte G, Taub E, Morris D, Vignolo M, McCulloch K. Reliability and validity of the upper-extremity Motor Activity Log-14 for measuring real-world arm use. *Stroke* 2005; 36:2493-6.
15. Kwon JS, Park MJ, Yoon IJ, Park SH. Effects of virtual reality on upper extremity function and activities of daily living performance in acute stroke: a double-blind randomized clinical trial. *Neuro Rehabilitation* 2012; 31:379-85.
16. Lee SH, Yoo WG. Comparison of the tibialis anterior and soleus muscles isolation ratios during the sit-to-stand movement in elderly people. *J Phys Ther Sci* 2017; 29:1019-20.
17. Deconinck FJ, Smorenburg AR, Benham A, Ledebt A, Feltham MG, Savelsbergh GJ. Reflections on mirror therapy: a systematic review of the effect of mirror visual feedback on the brain. *Neurorehabil Neural Repair* 2015; 29:349-61.
18. Rossiter HE, Borrelli MR, Borchert RJ, Bradbury D, Ward NS. Cortical mechanisms of mirror therapy after stroke. *Neurorehabil Neural Repair* 2015; 29:444-52.
19. Agnew ZK, Wise RJ, Leech R. Dissociating object directed and non-object directed action in the human mirror system; implications for theories of motor simulation. *PLoS One* 2012; 7:e32517.
20. Cattaneo L, Rizzolatti G. The mirror neuron system. *Arch Neurol* 2009; 66:557-60.
21. Kang YJ, Ku J, Kim HJ, Park HK. Facilitation of corticospinal excitability according to motor imagery and mirror therapy in healthy subjects and stroke patients. *Ann Rehabil Med* 2011; 35:747-58.
22. Dancause N, Barbay S, Frost SB, et al. Extensive cortical rewiring after brain injury. *J Neurosci* 2005; 25:10167-79.
23. Yun GJ, Chun MH, Park JY, Kim BR. The synergic effects of mirror therapy and neuromuscular electrical stimulation for hand function in stroke patients. *Ann Rehabil Med* 2011; 35:316-21.
24. Wu CY, Huang PC, Chen YT, Lin KC, Yang HW. Effects of mirror therapy on motor and sensory recovery in chronic stroke: a randomized controlled trial. *Arch Phys Med Rehabil* 2013; 94:1023-30.
25. Yoo IG, Jung MY, Yoo EY, *et al*. Effect of specialized task training of each hemisphere on interlimb transfer in individuals with hemiparesis. *Neuro Rehabilitation* 2013; 32:609-15.