ORIGINAL ARTICLE

Mirror Therapy Enhances Lower-Extremity Motor Recovery and Motor Functioning After Stroke: A Randomized Controlled Trial

Serap Sütbeyaz, MD, Gunes Yavuzer, MD, PhD, Nebahat Sezer, MD, B. Füsun Koseoglu, MD

ABSTRACT. Sütbeyaz S, Yavuzer G, Sezer N, Koseoglu F. Mirror therapy enhances lower-extremity motor recovery and motor functioning after stroke: a randomized controlled trial. Arch Phys Med Rehabil 2007;88:555-9.

Objective: To evaluate the effects of mirror therapy, using motor imagery training, on lower-extremity motor recovery and motor functioning of patients with subacute stroke.

Design: Randomized, controlled, assessor-blinded, 4-week trial, with follow-up at 6 months.

Setting: Rehabilitation education and research hospital.

Participants: A total of 40 inpatients with stroke (mean age, 63.5y), all within 12 months poststroke and without volitional ankle dorsiflexion.

Interventions: Thirty minutes per day of the mirror therapy program, consisting of nonparetic ankle dorsiflexion movements or sham therapy, in addition to a conventional stroke rehabilitation program, 5 days a week, 2 to 5 hours a day, for 4 weeks.

Main Outcome Measures: The Brunnstrom stages of motor recovery, spasticity assessed by the Modified Ashworth Scale (MAS), walking ability (Functional Ambulation Categories [FAC]), and motor functioning (motor items of the FIM instrument).

Results: The mean change score and 95% confidence interval (CI) of the Brunnstrom stages (mean, 1.7; 95% CI, 1.2–2.1; vs mean, 0.8; 95% CI, 0.5–1.2; P=.002), as well as the FIM motor score (mean, 21.4; 95% CI, 18.2–24.7; vs mean, 12.5; 95% CI, 9.6–14.8; P=.001) showed significantly more improvement at follow-up in the mirror group compared with the control group. Neither MAS (mean, 0.8; 95% CI, 0.4–1.2; vs mean, 0.3; 95% CI, 0.1–0.7; P=.102) nor FAC (mean, 1.7; 95% CI, 1.2–2.1; vs mean, 1.5; 95% CI, 1.1–1.9; P=.610) showed a significant difference between the groups.

Conclusions: Mirror therapy combined with a conventional stroke rehabilitation program enhances lower-extremity motor recovery and motor functioning in subacute stroke patients.

Key Words: Cerebrovascular accident; Feedback; Imagery; Motor skills; Rehabilitation.

From IVth Physical Medicine & Rehabilitation Clinic, Ankara Physical Medicine and Rehabilitation Education and Research Hospital, Ankara, Turkey (Sütbeyaz, Sezer, Köseoglu); Department of Physical Medicine & Rehabilitation, Ankara University Faculty of Medicine, Ankara, Turkey (Yavuzer); and Department of Rehabilitation Medicine, Erasmus University Medical Center, Rotterdam, The Netherlands (Yavuzer).

No commercial party having a direct financial interest in the results of the research supporting this article has or will confer a benefit upon the author(s) or upon any organization with which the author(s) is/are associated.

Reprint requests to Gunes Yavuzer, MD, PhD, Mustafa Kemal Mahallesi, Baris Sitesi 87. sok No: 24, Ankara 06800, Turkey, e-mail: *gunesyavuzer@hotmail.com.*

0003-9993/07/8805-11345$32.00/0
doi:10.1016/j.apmr.2007.02.034

STROKE IS THE LEADING CAUSE of serious long-term disability in adults. More than 60% of stroke survivors suffer from persistent neurologic deficits that impair activities of daily living.[1] Lower-extremity motor function after a stroke is often impaired, causing restrictions in functional mobility.[2,3] Traditionally, physical therapy for patients with hemiparesis in the weeks after their stroke consists of exercise therapy based on neuromuscular re-education, as well as on the practice of pre-walking functional tasks such as transfer activities, weight shifts in sitting or standing, and the maintenance of unassisted stance.[4] It has been shown that functional organization of the motor system, including the primary motor cortex, can be modulated by both ipsilateral limb movement and passive observation of movement of the contralateral limb.[5-7]

Mirror therapy is a relatively new therapeutic intervention that focuses on moving the unimpaired limb. It was first introduced by Ramachandran and Roger-Ramachandran[8] to treat phantom pain after amputation. Patients reported that they could move and relax the often-cramped phantom limb and experienced pain relief after mirror treatment. In a randomized crossover design study with chronic stroke patients, Altschuler et al[9] reported that range of motion and speed and accuracy of arm movement were improved with mirror therapy more than without. Stevens and Stoykov[10,11] also reported that stroke patients who trained with mirror therapy for 3 to 4 weeks had increased Fugl-Meyer Assessment scores, active range of motion, movement speed, and hand dexterity. Similarly, Sathian et al[12] found that 2 weeks of intense mirror therapy in chronic stroke patients resulted in a significant recovery of grip strength and hand movement of the paretic arm. This therapy has been used to treat phantom limb pain in amputee patients,[8] and in stroke patients with complex regional pain syndrome type I,[13] peripheral nerve injury,[14] brachial plexus avulsion,[15] and the paretic hand.[9,12] Mirror therapy in stroke patients involves performing movements of the unimpaired limb while watching its mirror reflection superimposed over the (unseen) impaired limb, thus creating a visual illusion of enhanced movement capability of the impaired limb.[10]

Functional brain imaging studies of healthy subjects suggest that excitability of the primary motor cortex ipsilateral to a unilateral hand movement is facilitated by viewing a mirror reflection of the moving hand.[16] Reorganization of motor functions immediately around the stroke site (ipsilesional) is likely to be important in motor recovery after stroke, and a contribution of other brain areas in the affected hemisphere is also possible.[17] Activation when a subject is doing motor tasks can also occur in the bilateral inferior parietal area, the supplementary motor area, and in the premotor cortex.[18,19] Furthermore, Luft et al[20] demonstrated that central adaptations occur in networks controlling the paretic as well as the nonparetic lower limb after stroke. Actions generated using motor imagery adhere to the same movement rules and constraints that physical movements follow, and the neural network involved in motor imagery and motor execution overlap, primarily in the premotor and parietal areas, basal ganglia, and cerebellum.[9,10,16]

In this study, we hypothesized that congruent visual feedback and motor imagery from the moving nonparetic lower extremity, as provided by a mirror, would help restore the integrity of cortical processing and thereby restore function in the affected lower extremity. We designed this randomized, controlled, assessor-blinded trial to evaluate the effects of mirror therapy using motor imagery training on lower-extremity motor recovery in patients with subacute stroke.

METHODS

Participants

We identified potential participants from an inpatient stroke rehabilitation ward. Two physiatrists (SS, NS) assessed the subjects to determine their eligibility and to obtain their written informed consent. The trial included 40 inpatients (23 men, 17 women) with hemiparesis after stroke (mean age, 63.4y; mean time since stroke, 3.7mo). Stroke was defined as an acute event of cerebrovascular origin causing focal or global neurologic dysfunction lasting more than 24 hours,[21] diagnosed by a neurologist, and confirmed by computed tomography or magnetic resonance imaging. Patients were required to meet the following criteria for inclusion in the study: (1) first episode of unilateral stroke with hemiparesis during the previous 12 months, (2) a score between 1 and 3 (inclusive) on the Brunnstrom stages of motor recovery of the lower extremity, (3) no severe cognitive disorders that would interfere with the study's purpose, and (4) ambulatory before stroke. The Ankara University Ethics Committee approved the protocol and all patients provided their written informed consent.

Sample Size

The required sample size was determined by using the pooled estimate of within-group standard deviations (SDs) of 4.9, obtained from the pilot data (n=10). Power calculations indicated that a sample of 40 subjects would provide an 80% (β=.20) chance of detecting a 20% (α=.05) difference in improvement between the groups.

Design

We used an assessor-blinded, randomized controlled design. The same investigator (SS), who was blinded to the treatment assignment, performed all the assessments. After baseline measurements were obtained, the patients were randomly assigned to either the mirror group (n=20) or the control group (n=20), using computer-generated random numbers (fig 1). Blocks were numbered, after which we used a random-number generator program to select numbers that established the sequence in which blocks were allocated to one or the other group. A physician who was blinded to the research protocol and was not otherwise involved in the trial conducted the random-number program.

Intervention

Both the mirror group and the placebo group participated in a conventional stroke rehabilitation program, 5 days a week, 2 to 5 hours a day, for 4 weeks. The conventional program is patient-specific and consists of neurodevelopmental facilitation techniques, physical therapy, occupational therapy, and speech therapy (if needed). The mirror group received an additional 30 minutes a day of a mirror therapy program consisting of nonparetic ankle dorsiflexion movements. Subjects were in a semiseating position on a bed, while the mirror board (40×70cm) was positioned between the legs perpendicular to the subject's midline, with the nonparetic leg facing the reflective surface.

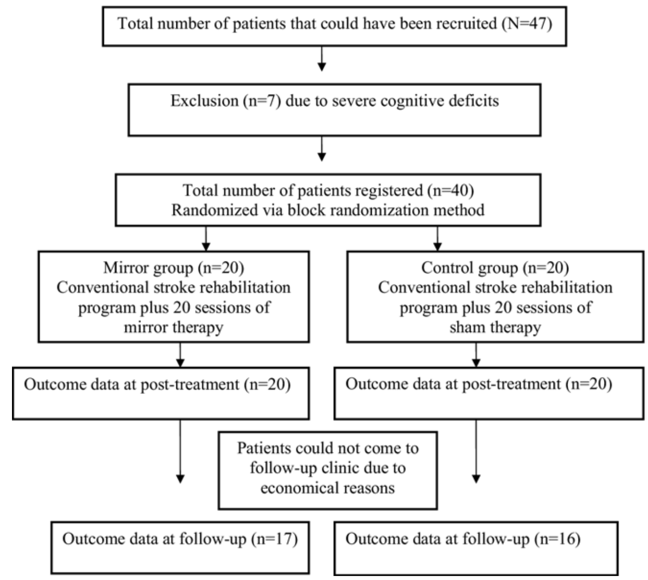

Fig 1. Flow diagram for randomized subject assignment in this study.

Subjects observed the reflection of the nonparetic leg while flexing and extending the ankle at a self-selected speed under supervision but without additional verbal feedback. The placebo group performed the same exercise for the same duration, but the nonreflecting side of the mirror was used.

Outcome Measures

Outcome was measured in terms of motor recovery (Brunnstrom stages), spasticity (Modified Ashworth Scale [MAS]), walking ability (Functional Ambulation Categories [FAC]), and motor functioning (motor items of FIM instrument). The measures were taken before treatment, at 1 month post-treatment, and at 6 months (follow-up).

Lower-Extremity Motor Recovery

We assessed lower-extremity motor recovery with the Brunnstrom stages.[22] The 6 grades of those stages for the lower extremity are: (1) flaccidity, (2) synergy development (minimal voluntary movements), (3) voluntary synergistic movement (combined hip flexion, knee flexion, and ankle dorsiflexion, both sitting and standing), (4) some movements deviating from synergy (knee flexion exceeding 90° and ankle dorsiflexion with the heel on the floor in the sitting position), (5) independence from basic synergies (isolated knee flexion with the hip extended and isolated ankle dorsiflexion with the knee extended in the standing position), and (6) isolated joint movements (hip abduction in the standing position and knee rotation with inversion and eversion of the ankle in the sitting position). We used the Brunnstrom stages because they reflect the underlying motor control based on clinical assessment of movement quality.

Spasticity

We used the MAS to grade the spasticity of the ankle flexor and extensor muscles. The MAS is a 5-point ordinal rating scale with good interrater reliability and is designed to measure muscle tone. Higher MAS scores indicate worse spasticity.[23]

Table 1: Characteristics of the 2 Study Groups

Variable	Mirror (n=20)	Control (n=20)	P
Age (y)	62.7±9.7	64.7±7.7	.36*
Sex (women/men)	10/10	7/13	.52†
Type of injury (ischemic/ hemorrhagic)	16/4	17/3	.50†
Paretic side (right/left)	6/14	7/13	.50†
Time since stroke (mo)	3.5±1.3	3.9±1.9	.44*
Mean Brunnstrom stages	2.4±0.7	2.5±1.0	.73†
Median Brunnstrom stages	3.0	3.0	
Mean MAS	2.6±0.5	2.3±0.7	.13†
Median MAS	3.0	2.0	
Mean FAC	1.9±0.5	2.0±0.7	.79†
Median FAC	2.0	2.0	
FIM motor score	48.3±5.5	50.2±11.6	.51*

NOTE. Values are mean ± SD, median, or number of patients.
*Student *t* test.
†χ^2 test.

Walking Ability

Walking ability was assessed with the FAC and the motor items of the FIM. The FAC is a reliable and valid assessment tool whose 6 categories provide information on the level of physical support patients need to ambulate safely both indoors and outdoors.[24] Our subjects were permitted to use walking devices (eg, canes) during the measurements.

Motor Functioning

The FIM is the functional status component of the Uniform Data System for Medical Rehabilitation.[25] It is widely used in rehabilitation centers and has properties useful to stroke investigators. It has 18 items that measure independent performance in self-care, sphincter control, transfers, locomotion, communication, and social cognition. FIM scores range from 1 to 7: a FIM item score of 7 is categorized as "complete independence," while a score of 1 indicated "complete dependence" (performs <25% of task). Scores below 6 mean that a subject requires supervision or assistance from another person.[26] We used the motor items of the FIM; the total score ranges from 13 (lowest) to 91 (highest). The reliability and validity of the Turkish version of the FIM has been well documented.[27]

Statistical Analysis

We analyzed the data using SPSS[a] for Windows. Groups were compared at baseline using the *t* test for independent samples for the continuous variables, and the chi-square test for categorical data. All outcome variables were normally distributed; for that reason we chose analyses of variance with repeated measures to test our hypothesis, with a between-subject factor at 2 levels (the 2 groups) and a within-subject factor at 3 levels (the time: pretreatment, post-treatment, follow-up). The interaction of group and time determined the efficacy of the mirror therapy on the outcome measures.

RESULTS

Demographic and clinical characteristics of the 40 participants, as well as baseline comparisons of the groups, are presented in table 1. None of the patients missed more than 2 scheduled sessions. Three patients from the mirror group and 4 patients from the control group could not attend the follow-up clinic for final evaluation because of socioeconomic reasons. We did not observe any adverse events. Baseline comparisons revealed that age, gender, injury characteristics, time since stroke, Brunnstrom stages, MAS, FIM motor, and FAC scores did not differ between the groups (P>.05). All assessed outcome parameters improved significantly in both groups after the treatment and continued to improve at follow-up (table 2). The mean change score and 95% confidence interval (CI) of the Brunnstrom stages (mean, 1.7; 95% CI, 1.2–2.1; vs mean, 0.8; 95% CI, 0.5–1.2; P=.002), as well as the FIM motor score (mean, 21.4; 95% CI, 18.2–24.7; vs mean, 12.5; 95% CI, 9.6–14.8; P=.001), showed significantly more improvement at follow-up in the mirror group than in the control group. Neither MAS (mean, 0.8; 95% CI, 0.4–1.2; vs mean, 0.3; 95% CI, 0.1–0.7; P=.102) nor FAC (mean, 1.7; 95% CI, 1.2–2.1; vs mean, 1.5; 95% CI, 1.1–1.9; P=.610) showed significant differences between the groups.

DISCUSSION

This study reveals that in our group of stroke patients, mirror therapy combined with a conventional rehabilitation program provides additional long-term benefits in terms of lower-extremity motor recovery and motor functioning. Several recent studies on paretic upper extremity, although undersized and not sufficiently controlled, have indicated that mirror therapy may be a promising tool with which to promote motor

Table 2: Motor Recovery, Spasticity, Walking Ability, and Motor Functioning Scores of Patients at Pretreatment, Post-Treatment, and Follow-Up

Parameter	Group	Pretreatment	Post-Treatment	Follow-Up	Δ (95% CI)	P
Brunnstrom stages						.002
	Mirror	2.4±0.7	3.5±0.8	4.2±0.8	1.7 (1.2–2.1)	
	Control	2.5±1.0	3.0±0.7	3.4±0.8	0.8 (0.5–1.2)	
MAS						.102
	Mirror	2.6±0.5	2.3±0.5	1.8±0.7	0.8 (0.4–1.2)	
	Control	2.3±0.7	2.2±0.7	1.9±0.7	0.3 (0.1–0.7)	
FAC						.610
	Mirror	1.9±0.5	2.8±0.6	3.6±0.9	1.7 (1.2–2.1)	
	Control	2.0±0.7	2.9±0.7	3.5±0.9	1.5 (1.1–1.9)	
FIM motor						.001
	Mirror	48.3±5.5	65.9±4.8	69.9±5.9	21.4 (18.2–24.7)	
	Control	50.2±11.6	61.7±14.6	62.9±12.8	12.5 (9.6–14.8)	

NOTE. Values are mean ± SD. *P* values were obtained using analysis of variance for repeated measures.
Abbreviation: Δ, mean change at follow-up from baseline.

recovery, mobility, muscle strength, dexterity and functionality after stroke.[9,10] To our knowledge, ours is the first study to investigate the effects of mirror therapy on the paretic lower extremity.

It is well known that an increased inflow of signals from sensory modalities via various ways can enhance plasticity of the brain.[28] Sensory processes (including vision, audition, proprioception, touch, and pressure) can mediate feedback information that is available as a result of movement. Verbal cueing and coaxing by therapists,[29] visual and auditory feedback from electromyography,[30] forceplate (balance and weight shift training), computer screen (virtual reality and web-based telerehabilitation),[31,32] and kinematic feedback from an electrogoniometer[33] are the most common examples used for stroke rehabilitation. In this study, we used mirror therapy to give visual feedback to the patients to enhance lower-extremity motor recovery. Studies have shown that mirror illusions have measurable effects on brain activity.[16-20] Altschuler et al[9] hypothesized that mirror therapy provides visual input of a normal movement of the affected arm in stroke patients, which may compensate for a decreased or absent proprioceptive input. Stevens and Stoykov[10,11] defined mirror therapy as a form of visually guided motor imagery, which is the mental performance of a movement without overt execution of that movement. Extensive clinical, neurophysiologic, and neuroimaging evidence demonstrates that motor imagery involves the same neural networks as motor execution.[34] Another possible mechanism is the involvement of the mirror neuron system.[16] Mirror neurons are bimodal visuomotor neurons that are active during action observation, mental stimulation (imagery), and action execution. For example, it has been shown that passive observation of an action facilitates M1 excitability of the muscles used in that specific action.[35] Mirror neurons are now generally understood to underlie the learning of new skills by visual inspection of the skill.

In our study, all subjects performed voluntary ankle dorsiflexion movements on their nonparetic side during the therapy sessions. We selected ankle dorsiflexion because it represents selective motor control in the lower extremity after stroke. Ankle movement training is known to facilitate brain reorganization, and the angle paradigm may serve as an ongoing physiologic assay of the optimal type, duration, and intensity of rehabilitative gait training.[36] In the lower extremity, voluntary ankle dorsiflexion is a way of indicating the achievement of selective motor control.[22] Once voluntary movement is achieved (Brunnstrom motor recovery stage II recovery or beyond), synergistic patterns are then modified to selective (out-of-synergy) patterns.

In this study, in contrast to motor recovery and motor functioning, the between-group difference was not significant for walking ability and spasticity. Spasticity has a complex pathophysiology that enhanced visual feedback may not be sufficient to influence or control. Walking is also a complex performance and requirements for normal gait include (but are not limited to) muscle strength, coordination, balance, endurance, etc. For motor learning to be successful, the desired motor task must be practiced in a pattern that is as close to normal as possible[37] and practiced intensively.[38] Our intervention did not provide for practice of a gait pattern that is close to normal. It is believed that repeated task-specific protocols induce brain reorganization that facilitates functional improvements.[39] Cognitive involvement, functional specificity, and progressive complexity of the tasks being trained are the key variables of motor training and cortical reorganization.[40] We did not increase the complexity level of the training in this study. Another explanation for the lack of effect on walking ability may be that the 4 weeks (20 sessions, a total of 10h) in which the mirror therapy was applied may have been too short to produce significant benefits for such a complex activity. Kwakkel[41] reported that a minimum of at least 16 hours augmentation was necessary to determine the required amount of practice needed to affect function. Because there are very few studies on the use of mirror therapy in patients with stroke, there is no widely accepted agreement on the duration, timing, and application of such a program.

Our results confirm that visual feedback via a mirror is a simple, inexpensive and, most importantly, a patient-specific treatment. We believe that incorporating mirror therapy into the conventional rehabilitation program at an early stage of treatment, and applying it for a long period of time (perhaps continuing the therapy at home after discharge), may be beneficial in improving the effects and outcome on lower-extremity motor recovery and function. The limitations of this study are the relatively small study population and the fact that we did not use imaging techniques (eg, functional magnetic resonance imaging, positron emission tomography) that might have demonstrated brain reorganization after therapy.

CONCLUSIONS

Mirror therapy combined with a conventional rehabilitation program enhanced lower-extremity motor recovery and functioning in our subacute stroke inpatients.

References

1. Jongbloed L. Prediction of function after stroke: a critical review. Stroke 1986;17:765-76.
2. Olney SJ, Richards CL. Hemiparetic gait following stroke, part I: characteristics. Gait Posture 1996;4:136-48.
3. Perry J, Garrett M, Granley JK, Mulroy SJ. Classification of walking handicap in stroke population. Stroke 1995;26:982-9.
4. Ryerson S, Levit K. Functional movement reduction: a complementary model for stroke rehabilitation. New York: Churchill Livingstone; 1997.
5. Liepert J, Dettmers C, Terborg C, Weiller C. Inhibition of ipsilateral motor cortex during phasic generation of low force. Clin Neurophysiol 2001;112:114-21.
6. Muellbacher W, Facchini S, Boroojerdi B, Hallett M. Changes in motor cortex excitability during ipsilateral hand muscle activation in humans. Clin Neurophysiol 2000;111:344-9.
7. Muellbacher W, Ziemann U, Boroojerdi B, Cohen L, Hallett M. Role of the human motor cortex in rapid motor learning. Exp Brain Res 2001;136:431-8.
8. Ramachandran VS, Roger-Ramachandran D. Synaesthesia in phantom limbs induced with mirrors. Proc R Soc Lond B Biol Sci 1996;263:377-86.
9. Altschuler EL, Wisdom SB, Stone L. Rehabilitation of hemiparesis after stroke with a mirror. Lancet 1999;353:2035-6.
10. Stevens JA, Stoykov ME. Using motor imagery in the rehabilitation of hemiparesis. Arch Phys Med Rehabil 2003;84:1090-2.
11. Stevens JA, Stoykov ME. Simulation of bilateral movement training through mirror reflection: a case report demonstrating an occupational therapy technique for hemiparesis. Top Stroke Rehabil 2004;11:59-66.
12. Sathian K, Greenspan AI, Wolf SL. Doing it with mirrors: a case study of a novel approach to neurorehabilitation. Neurorehabil Neural Repair 2000;14:73-6.
13. McCabe CS, Haigh RC, Ring EF, Halligan PW, Wall PD, Blake DR. A controlled pilot study of the utility of mirror visual feedback in the treatment of complex regional pain syndrome (type 1). Rheumatology 2003;42:97-101.
14. Rosen B, Lundborg G. Training with a mirror in rehabilitation of the hand. Scand J Plast Reconstr Surg Hand Surg 2005;39:104-8.
15. Giraux P, Sirigu A. Illusory movement of the paralyzed limb restores motor cortex activity. Neuroimage 2003;20:S107-11.

16. Garry MI, Loftus A, Summers JJ. Mirror, mirror on the wall: viewing a mirror reflection of unilateral hand movements facilitates ipsilateral M1 excitability. Exp Brain Res 2005;163:118-22.
17. Thirumala P, Hier DB, Patel P. Motor recovery after stroke: lessons from functional brain imaging. Neurol Res 2002;24:453-8.
18. Nelles G, Spiekermann G, Jueptner M, et al. Reorganization of sensory and motor systems in hemiplegic stroke patients. A positron emission tomography study. Stroke 1999;30:1510-6.
19. Weiller C, Chollet F, Friston KJ, Wise RJ, Frackowiak RS. Functional reorganization of the brain in recovery from striatocapsular infarction in man. Ann Neurol 1992;31:463-72.
20. Luft AR, Forrester L, Macko RF, et al. Brain activation of lower extremity movement in chronically impaired stroke survivors. Neuroimage 2005;26:184-94.
21. Foulkes MA, Wolf PA, Price TR, Mohr JP, Hier DB. The stroke data bank: design, methods, and baseline characteristics. Stroke 1988;19:547-54.
22. Sawner K, Lavigne J. Brunnstrom's movement therapy in hemiplegia: a neurophysiological approach. Philadelphia: JB Lippincott; 1992.
23. Bohannon RW, Smith MB. Interrater reliability of a modified Ashworth scale of muscle spasticity. Phys Ther 1987,67:206-7.
24. Collen FM, Wade DT, Bradshaw CM. Mobility after stroke: reliability of measures of impairment and disability. Int Disabil Stud 1990;12:6-9.
25. Granger CV, Gresham GE. New developments in functional assessment. Phys Med Rehabil Clin N Am 1993;4:417-99.
26. Keith RA, Granger CV, Hamilton BB, Sherwin FS. The Functional Independence Measure: a new tool for rehabilitation. Adv Clin Rehabil 1987;1:6-18.
27. Kucukdeveci AA, Yavuzer G, Elhan AH, Sonel B, Tennant BA. Adaptation of the Functional Independence Measure for use in Turkey. Clin Rehabil 2001;15:311-9.
28. Hamdy S, Rothwell JC, Aziz Q, Singh KD, Thompson DG. Long-term reorganization of human motor cortex driven by short-term sensory stimulation. Nat Neurosci 1998;1:64-8.
29. van Vliet PM, Wulf G. Extrinsic feedback for motor learning after stroke: what is the evidence? Disabil Rehabil 2006;28:831-40.
30. Moreland JD, Thomson MA, Fuoco AR. Electromyographic biofeedback to improve lower extremity function after stroke: a meta-analysis. Arch Phys Med Rehabil 1998;79:134-40.
31. Merians AS, Jack D, Boian R. Virtual-reality augmented rehabilitation for patients following stroke. Phys Ther 2002;82:898-915.
32. Reinkensmeyer DJ, Pang CT, Nessler JA, Painter CC. Web-based telerehabilitation for the upper extremity after stroke. IEEE Trans Rehabil Eng 2002;10:102-8.
33. Morris ME, Matyas TA, Bach TM, Goldie PA. Electrogoniometric feedback: its effect on genu recurvatum in stroke. Arch Phys Med Rehabil 1992;73:1147-57.
34. Mulder T. The role of motor imagery in learning a totally novel movement. Exp Brain Res 2004;154:211-7.
35. Fadiga L, Craighero L. Electrophysiology of action representation. J Clin Neurophysiol 2004;21:157-69.
36. Dobkin BH, Firestine A, West M, Saremi K, Woods R. Ankle dorsiflexion as an fMRI paradigm to assay motor control for walking during rehabilitation. Neuroimage 2004;23:370-81.
37. Daly JJ, Roenigk KL, Butler KM, et al. Response of sagittal plane gait kinematics to weight-supported treadmill training and functional neuromuscular stimulation following stroke. J Rehabil Res Dev 2004;41:807-20.
38. Teasell R, Bitensky J, Salter K, Bayona NA. The role of timing and intensity of rehabilitation therapies. Top Stroke Rehabil 2005; 12:46-57.
39. Morris DM, Taub E, Mark VW. Constraint-induced movement therapy: characterizing the intervention protocol. Eur Medicophys 2006;42:257-68.
40. Carey JR, Bhatt E, Nagpal A. Neuroplasticity promoted by task complexity. Exerc Sport Sci Rev 2005;33:24-31.
41. Kwakkel G. Impact of intensity of practice after stroke: issues for consideration. Disabil Rehabil 2006;28:823-30.

Supplier

a. Version 11.5; SPSS Inc, 233 S Wacker Dr, 11th Fl, Chicago, IL 60606.