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ADDITION OF INTENSIVE REPETITION OF FACILITATION EXERCISE TO MULTIDISCIPLINARY REHABILITATION PROMOTES MOTOR FUNCTIONAL RECOVERY OF THE HEMIPLEGIC LOWER LIMB

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Objective: **To evaluate the effects of the intensive repetition of movements elicited by the facilitation technique to improve voluntary movement of a hemiplegic lower limb in patients with brain damage.**
Design: **A multiple-baseline design (A-B-A-B: A without specific therapy, B with specific therapy) across individuals.**
Patients: **The sample comprised 22 subjects with stroke and 2 brain tumour-operated subjects (age: 50.7 ± 9.6 years, time after onset: 7.1 ± 2.6 weeks). They were selected from among 165 patients with stroke who were admitted to our rehabilitation centre from September 1, 1995 to March 31, 1997.**
Methods: **Two 2-week facilitation technique sessions (more than 100 repetitions a day for each of 5 kinds of movement) were applied at 2-week intervals in patients with hemiplegia, who were being treated with continuous conventional rehabilitation exercise without the facilitation technique for hemiplegia. Motor function of the affected lower limb (Brunnstrom Recovery Stage of hemiplegia, the foot-tap test and the strength of knee extension/flexion) and walking velocity were evaluated at 2-week intervals.**
Results: **Significant improvements in Brunnstrom Stage, foot-tapping and the strength of knee extension/flexion of the affected lower limb were seen after the first conventional rehabilitation exercise session and after the first and second facilitation technique and conventional rehabilitation exercise sessions. The improvements after facilitation technique and conventional rehabilitation exercise sessions were significantly greater than those after the preceding conventional rehabilitation exercise sessions.**
Conclusion: **Intensive repetition of movement elicited by the facilitation technique (chiefly proprioceptive neuromuscural facilitation pattern, stretch reflex and skin-muscle reflex) improved voluntary movement of a hemiplegic lower limb in patients with brain damage.**

Key words: hemiplegia, exercise therapy, functional recovery, facilitation technique.

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INTRODUCTION

Various approaches to stroke rehabilitation, such as the facilitation technique including proprioceptive neuromuscular facilitation (PNF) techniques (1), Brunnstrom's approach (neurophysiological approach) (2), Bobath's approach (neurodevelopmental approach) (3), therapeutic electric stimulation (4), electromyographic biofeedback (5), intensive rehabilitation therapy (6) and constraint-induced therapy (7), have been studied to improve the functional recovery of hemiplegia due to brain damage. Facilitation techniques are supported by neurophysiological theory and many neurophysiological animal studies, and have commonly been used to improve the recovery of voluntary movement of hemiplegic limbs. However, there is some controversy surrounding usual facilitation techniques with regard to their underlying neurophysiological rationale and efficacy in stroke rehabilitation. Specifically, there is insufficient evidence that these techniques are superior to conventional exercise therapies (9–11). However, functional improvements seen with intensive rehabilitation therapy (12), repetitive training of isolated movements (13) and constraint-induced therapy (7) have suggested that therapeutic exercise that includes facilitation techniques may improve motor function of hemiplegic limbs if the facilitation techniques are of adequate intensity and quality, and especially if they involve repetition of the voluntary movements to be recovered.

In adult primates, repetitive motor skill exercise with the hand induced changes in motor representation in the primary motor cortex (14) that were proportional to how often the exercise was repeated. Furthermore, functional recovery and reorganization in the adjacent intact cortex after brain infarction were accelerated by repeated intentional training of the hemiplegic hand (15). Such brain plasticity after brain damage has also been observed in humans (16).

For the repeated voluntary movement of hemiplegic limbs to strengthen neural networks to realize voluntary movement, and especially when they are influenced by a synergic pattern, it is necessary to elicit directed voluntary movement free from synergy. The degree of the recovery of voluntary movement of hemiplegic limbs may depend on the repetition of voluntary movement assisted by facilitation techniques. However, there have been few reports (6, 13, 17, 18) in humans on the effects of the repetition of specific therapeutic exercise on the recovery of the voluntary movement of hemiplegic limbs.

In the present study, we investigated whether the intensive repetition of voluntary movement of hemiplegic lower limbs elicited by facilitation techniques (IRF), in addition to conventional rehabilitation exercise, would promote greater motor functional recovery of hemiplegic lower limbs than conventional rehabilitation exercise (CRE) alone.

METHODS

Subjects

Patients with hemiplegia were recruited from among in-patients who had been admitted to Kirishima Rehabilitation Center of Kagoshima University, Japan, from September 1, 1995 to March 31, 1997.

The subjects consisted of 24 in-patients (18 men and 6 women) recruited from among 165 patients with hemiplegia. Their diagnosis was cerebral haemorrhage (17 patients), cerebral infarction (5 patients) and post-operative brain tumour (2 patients). The average age was 50.7 ± 9.6 years (33–70 years), the duration after onset was 7.1 ± 2.6 weeks (3–12 weeks) and the median and quartiles of the Brunnstrom Stage of the hemiplegic lower limb were Stage 3.0, 3–4 (Stage 2–4). Fourteen patients had right hemiplegia and 10 had left hemiplegia (Table I). The exclusion criteria were: (i) more than 71 years old; (ii) more than 13 weeks since onset of stroke or operation; (iii) without a normal gait prior to the onset of stroke or brain tumour; (iv) a medical condition that limited the completion of IRF and CRE; e.g. severe cardiopulmonary diseases or disability of joint including hip fracture and replacement of hip/knee joints; (v) severe aphasia that made it impossible to follow the verbal instructions of the therapist in IRF; (vi) lesions in bilateral hemispheres, severe sensory disturbance, dementia or visuo-spatial hemineglect that interfered with the outcome assessments or that limited attention or learning capacity; and (vii) had not yet completed hyperosmolar therapy (glycerol or mannitol) and hyperbaric oxygen therapy. The procedures complied with the *1975 Declaration of Helsinki*, as revised in 1983. Informed consent was obtained from all of the subjects according to the ethics rules of the hospital.

Procedure and treatment protocol

A multiple-baseline design (A-B-A-B: A without specific therapy, B with specific therapy) across individuals was used. All of the subjects received continuous CRE therapy for hemiplegia throughout the 8-week study period. In addition, the subjects also participated in 2 2-week sessions of IRF for the hemiplegic lower limb in the 3rd and 4th weeks and 7th and 8th weeks after admission (Fig. 1). One physician and 3 physiotherapists participated in training sessions, compiled treatment specifications for CRE and IRF and standardized IRF.

Table I. *Characteristics of subjects (*n *= 24)*

Characteristic	
Age, years (mean, SD and range)	50.7 (9.6, 33–70)
Gender, Male/Female (*n*)	18/6
Diagnosis (n)	
Haemorrhage	17
Infarction	5
Tumour operation	2
Site of lesion (n)	
Basal ganglia	19
Basal G-cortex	3
Cortex	2
Side of hemiplegia	
Right/left	14/10
Time since onset or operation, weeks (mean, SD and range)	7.1 (2.6, 3–12)
Brunnstrom Stage of hemiplegic lower limb (median, quartiles and range)	3.0 (3–4, 2–4)

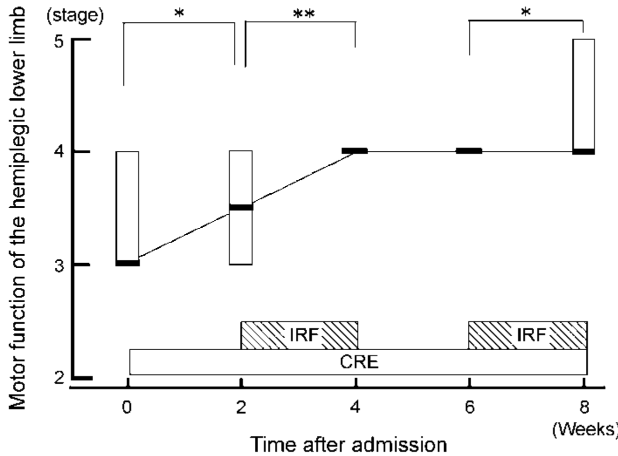

Fig. 1. Motor functional recovery of hemiplegic lower limbs with conventional rehabilitation exercise (CRE) and intensive repetition of facilitation (IRF) exercise. Boxes show median (50th percentile) and interquartile (25th and 75th percentiles) values of Brunnstrom Stage for all subjects. $*p < 0.05$ and $**p < 0.01$ between indicated periods.

The CRE sessions consisted of therapeutic exercise with a physiotherapist for 45 minutes and voluntary training for 2–3 hours, and were performed once a day for 5 days a week. Therapeutic exercise included passive range-of-motion exercise, mat exercise, standing up and sitting down, and ambulation with assistive devices or support. The number of repetitions in the mat exercise and the distance in walking were increased as the physical performance of the patient progressed. Facilitation techniques involving IRF were limited to 1 kind of exercise and less than 20 repetitions a day. Occupational therapy (activities of daily living (ADL), vocational, perceptual and functional activity training), speech therapy and recreational activity were also performed depending on the individual's needs. All patients were allowed to engage in voluntary training from 09.00 h to 17.00 h, except for a 1-hour lunch period, in a training room.

Neural block, electrical treatment and changes in the dose of muscle relaxant were not applied during this study.

The IRF in IRF–CRE sessions consisted of 5 kinds of specific exercise patterns for the hemiplegic lower limb selected from among 7 specific exercise patterns (see below) to promote motor functional recovery of the hemiplegic lower limb and to enable the patient to perform specific motions in walking, and especially to improve the Trendelenburg gait, swing of the hemiplegic lower limb and spasticity preceding heel strike. The 5 specific exercise patterns for the hemiplegic lower limb were changed as hemiplegia improved. Each exercise was performed with the assistance of a physiotherapist or physician and was repeated 100 times a day (5 days a week). The patients were instructed to concentrate their visual attention on their lower limb movements and to make submaximal effort to avoid strong contraction of non-targeted muscles.

The techniques adopted in this study were according to PNF (1), Brunnstrom (2) and Bobath (3) and were modified.

1. Hip extension/flexion with the knee flexed at 90 degrees in the side-lying lateral position (preparation for point 6 below).
2. Hip external rotation/internal rotation with the knee flexed at 10 degrees in the supine position (preparation for point 6 below).
3. Hip flexion/adduction/external rotation – hip extension/abduction/internal rotation with the knee at 135 degrees in the supine position (preparation for point 6 below).
4. Knee extension/flexion with the hip flexed at 90 degrees in the sitting position (Brunnstrom's method) or isotonic movements with Cybex (extension 1 kg/flexion 1 kg).
5. Ankle extension/dorsiflexion in the sitting or supine position (Brunnstrom's method).
6. Hip flexion/adduction/external rotation, knee flexion with the ankle in dorsiflexion – hip extension/abduction/internal rotation, knee

extension with the ankle flexed at 0 degrees in the supine position. During hip extension/abduction/internal rotation, knee extension, when hip adduction and ankle extension occurred, this movement was stopped and reciprocal movement was initiate with the ankle quickly extended (PNF).

7. Holding the ankle flexed at 0 degrees, when the hip and knee were passively extended from 90 degrees to 0 degrees in the upright position (Bobath's method).

To confirm completion of the exercise program, each patient had a checklist that showed the program of voluntary training (kinds of exercise and number of repetitions) and the selected facilitation techniques for IRF. Upon completion of an item in the training program, the list was checked by the physiotherapist or physician who had administered the treatment or supervised the training.

Assessments of functional recovery

Four physical parameters and a physical ability of the whole body were measured at admission and pre/post IRF and CRE sessions.

The Brunnstrom Stage of Recovery from hemiplegia in the lower limbs was used to evaluate the degree of voluntary movement free from synergia. All rating was according to the original descriptions (2).

The foot-tap test (19) was used to evaluate functional movement of the foot, and the co-ordination of ankle dorsiflexion and extension. The number of foot taps was measured in a sitting position with the hemiplegic lower limb stabilized at the knee and ankle by the hands of the evaluator. The starting position was with the knee flexed at 90 degrees and the ankle flexed at 0 degrees. After 5 minutes of rest in the sitting position, the subject was asked to tap their foot as fast as possible without lifting the heel from the floor. The number of completed taps with lifting of both the toe and ball in a 30-second period was recorded and the best performance in 2 repetitions was used for analysis.

The isometric muscle strength of knee flexion and extension in a movement pattern free from synergy was measured using a Cybex 6000 dynamometer (Cybex International, Inc., Medway, MA, USA) in a sitting position. The subject was stabilized with the hip joint at 90 degrees and the knee at 60 degrees with a belt in accordance with the Cybex instruction manual (20). The subject was allowed 3 practice repetitions before data-recording. After a 1-minute rest, the subject was asked to push/pull as hard as possible for 3 seconds. The best peak torque (body weight ratio: %) in 2 trials was used for analysis.

Walking velocity (21) was evaluated as a physical ability of the whole body, including both the hemiplegic and unaffected sides of the body. The maximum walking velocity was measured by timing subjects over 10 metres with a stopwatch. The subjects were able to use walking aids and walked as fast as possible, with an assistant prepared to help in case of a fall. The best time in 3 trials was used for analysis.

Evaluation

Physical functions were evaluated by physiotherapists (Brunnstrom Stage of Recovery from hemiplegia and walking velocity) who provided physical therapy and 1 physician (foot-tap test and isometric muscle strength of knee flexion and extension) during the study. Blind evaluations were not used, but the physiotherapists and the physician were blind to each other's measurement results throughout the study. Before the study, the evaluators discussed any difficulties with scoring items to obtain a consensus to minimize intra-evaluator discrepancy and observer bias, and to conduct all evaluations objectively.

Statistics

To determine: (i) whether significant changes in motor function occurred during CRE–IRF and CRE sessions; and (ii) whether additional IRF promoted greater motor functional recovery than CRE alone, (i) changes in functional parameters in 2-week sessions of IRF–CRE and CRE were evaluated statistically and (ii) changes in motor functional parameters in 2-week IRF and CRE sessions were compared with those in the preceding CRE session. The data were analysed using a non-parametric test (Wilcoxon's non-parametric test and 1 sample sign test) because the data had a wide and discontinuous distribution. Differences were considered to be statistically significant at $p < 0.05$.

RESULTS

Each physical parameter was determined before and after CRE/IRF and CRE sessions.

Brunnstrom Stage of Recovery from hemiplegia

As shown in Fig. 1, in all of the subjects, the Brunnstrom Stage of Recovery from hemiplegia significantly improved from 3.0, 3–4 (median and quartiles) to 3.5, 3–4 ($p < 0.05$) after the first 2-week CRE session. After the first 2-week IRF and CRE session, it improved further from to 3.5, 3–4 to 4.0, 4–4 ($p < 0.01$). The difference in improvement between the first IRF–CRE session and the first CRE session was significant ($p < 0.01$). Although no further improvement was observed after the second CRE session (from 4.0, 4–4 to 4.0, 4–4; n.s.), a significant improvement was observed after the second IRF–CRE session (from 4.0, 4–4 to 4.0, 4–5; $p < 0.04$). Again, greater improvement was seen after the second IRF–CRE session than after the second CRE session, however, this difference was not statistically significant ($p < 0.08$). The combined improvements in the 2 IRF–CRE sessions (1.0, 0–1) were significantly ($p < 0.01$) greater than those in the 2 CRE sessions (0.0. 0–0).

Improvements of more than 2 Brunnstrom Stages were observed in 5 patients in the combined IRF–CRE sessions, but not in any of the patients in combined CRE sessions. A decrease of 1 Brunnstrom Stage was observed in 2 patients in the second CRE session.

Foot-tapping

The number of foot taps in 30 seconds increased by 3.2 ± 9.0 taps (n.s.) after the first CRE session and by 6.0 ± 8.1 taps ($p < 0.01$) after the first IRF–CRE session (Fig. 2). These values after the second CRE and IRF–CRE sessions were -0.1 ± 6.1 taps (n.s.) and 4.9 ± 7.0 taps ($p < 0.01$), respectively. Each improvement in an IRF–CRE session was greater than that in the

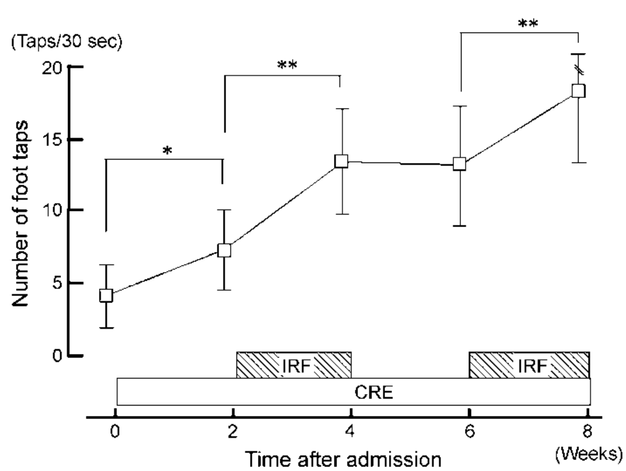

Fig. 2. Foot-tapping with conventional rehabilitation exercise (CRE) and intensive repetition of facilitation exercise (IRF). Number of foot taps in 30 seconds (mean and SE). *$p < 0.05$ and **$p < 0.01$ between the indicated periods.

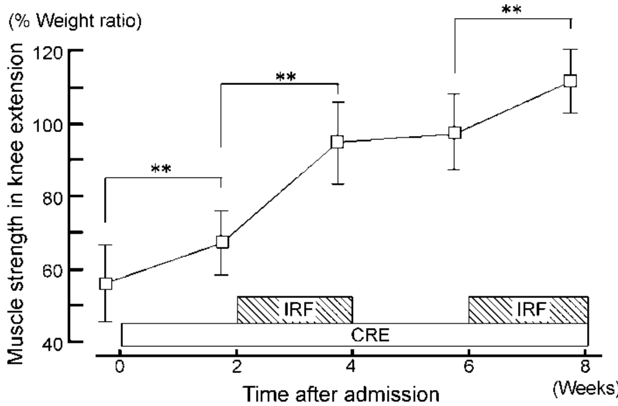

Fig. 3. Isometric muscle strength in knee extension of hemiplegic lower limbs with conventional rehabilitation exercise (CRE) and intensive repetition of facilitation exercise (IRF). Values represent mean values and SE. *$p < 0.05$ and **$p < 0.01$ between the indicated periods.

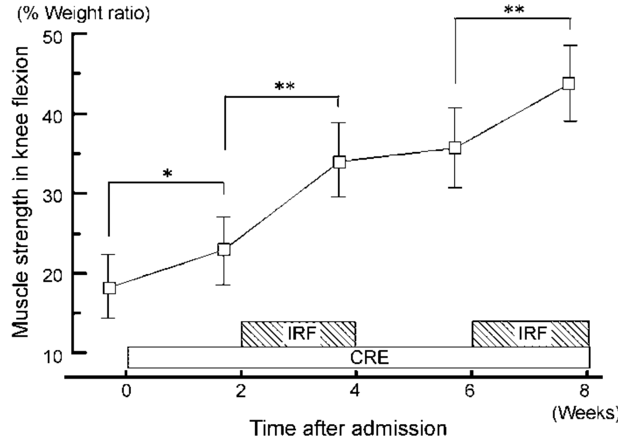

Fig. 4. Isometric muscle strength in knee flexion of hemiplegic lower limbs with conventional rehabilitation exercise (CRE) and intensive repetition of facilitation exercise (IRF). Values represent mean values and SE. *$p < 0.05$ and **$p < 0.01$ between the indicated periods.

preceding CRE session, but only the difference between the second CRE and IRF–CRE sessions was statistically significant ($p < 0.05$). The combined improvements in the IRF–CRE sessions (11.0 ± 12.1 taps) were significantly ($p < 0.01$) greater than those in the 2 CRE sessions (3.1 ± 10.2 taps).

Isometric muscle strength of knee extension/flexion

Isometric muscle strength of knee extension following CRE–IRF and CRE improved by 16.7 ± 17.5% ($p < 0.01$) and 27.2 ± 26.7% ($p < 0.01$) in the first session and 2.7 ± 17.0% (NS) and 14.4 ± 20.5% ($p < 0.01$) in the second session, respectively (Fig. 3). The improvement after the second IRF–CRE session was significantly ($p < 0.01$) greater than that after the second CRE session. The combined improvements in the 2 IRF–CRE sessions (42.0 ± 30.7%) were significantly ($p < 0.01$) greater than those in the 2 CRE sessions (19.6 ± 25.5%).

Isometric muscle strength of knee flexion improved by 4.2 ± 9.7% ($p < 0.05$) and 9.0 ± 16.2% ($p < 0.01$) with the first CRE–IRF and CRE sessions and by 0.3 ± 9.8% (n.s.) and 8.0 ± 10.9% ($p < 0.01$) with the second sessions, respectively (Fig. 4). The improvement with the second session of IRF–CRE was significantly ($p < 0.01$) greater than that with the second session of CRE. The combined improvements in the 2 IRF–CRE sessions (19.3 ± 20.6%) were greater than those in the 2 CRE sessions (9.2 ± 15.2%), but the difference between the 2 IRF–CRE sessions and the 2 CRE sessions was not statistically significant ($p < 0.08$).

Walking velocity

The decrease in the time required to walk 10 metres following CRE–IRF and CRE after the recovery of ambulation is shown in Fig. 5. The time required decreased by 5.9 ± 12.1 seconds (n.s.) and 8.1 ± 8.4 seconds ($p < 0.01$) with the first CRE–IRF and CRE sessions, and by 6.0 ± 8.0 seconds ($p < 0.01$) and 2.6 ± 4.2 s ($p < 0.02$) with the second CRE–IRF and CRE sessions, respectively. The cumulative decrease in the time required to walk 10 metres following 2 CRE and 2 IRF–CRE sessions after the recovery of ambulation was 6.9 ± 12.3 seconds (n.s.) and 10.9 ± 11.1 s ($p < 0.001$), respectively. The difference between the 2 CRE and 2 IRF–CRE sessions was not statistically significant. The number of ambulatory patients increased from 9 on admission to 24 after the second IRF–CRE session.

DISCUSSION

Significant improvements in motor function of the hemiplegic lower limb were seen after the intensive repetition of voluntary

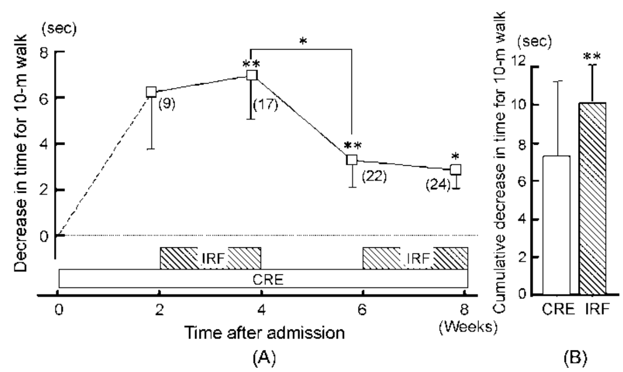

Fig. 5. Changes in gait speed with conventional rehabilitation exercise (CRE) and intensive repetition of facilitation exercise (IRF). The decrease in the time needed for a 10-metre walk following each session is shown on the vertical axis in (A). (□) indicates the number of measured patients who were ambulatory at the beginning of each session. The cumulative decrease in the time required to walk 10 metres following 2 CRE and 2 IRF–CRE sessions is shown on the vertical axis in (B). Values represent mean and SE. *$p < 0.05$ and **$p < 0.01$ indicate statistically significant decreases in the time needed for a 10-metre walk for a particular session or differences between indicated sessions.

movement elicited by facilitation technique, and these improvements were significantly greater than those after corresponding CRE sessions without IRF.

In this study, instead of a randomized control design, a multiple-baseline design (A-B-A-B: A without specific therapy, B with specific therapy) across individuals was used because: (i) there were not enough patients to exclude heterogeneity between study groups; and (ii) for ethical reasons we could not withhold rehabilitative therapy to create a control group. The effects of the aetiology of the brain injury and the lesion site on functional improvement were not analysed because almost all of the subjects showed a similar aetiology and a similar site of lesions due to the selection criteria.

Recently, the dosage and contents of physiotherapy have been considered to be critical factors in determining the pattern of recovery from stroke (22, 23), and have sometimes been shown to be beneficial for motor function recovery (12, 24). Neurophysiological studies have suggested that the repetition of identical movements is crucial for motor learning (25). Good motor functional recovery of a hemiplegic limb may depend on the elicitation of voluntary movements free from synergy, especially of movements to be recovered, and the intensive repetition of such movements (13).

In this study, facilitation techniques were used to promote motor functional recovery in hemiplegia by eliciting voluntary movements free from synergy. However, there is insufficient evidence that usual facilitation techniques are superior to traditional exercise therapies that exclude facilitation techniques (6–8) because of inadequate study design (small number of sample subjects and no control group), insufficient therapeutic content of facilitation techniques and their repetition, or inadequate evaluation of the improvement of hemiplegia itself. The Bobath method has been used as therapeutic exercise or as a control for new treatments, and has often failed to give superior results compared with other treatments (5, 6, 18, 26). Recently, changes in motor cortical excitability, induced by repetitive motor action or physiotherapeutic facilitation techniques, have been demonstrated by transcranial magnetic stimulation (27). The most prominent effects were observed when the muscle itself was voluntarily activated (28). The facilitation techniques in this study were mainly selected from Brunnstrom's approach and PNF, since these techniques are useful for eliciting and realizing directed voluntary movements and enable the intensive repetition of such elicited movements.

Although blind evaluations were not used due to the limited number of staff, the results of the measurements were thought to be reliable because: (i) the parameters in this study could be measured objectively; (ii) all evaluations were discussed in advance to minimize intra-evaluator discrepancy and conducted following a description of assessment methods; and (iii) the evaluator/patient pairs did not change throughout the study.

In this study, the improvement in motor function of hemiplegic lower limbs with the IRF and CRE sessions was significantly greater than that in the preceding CRE session. It is difficult to know whether the improvements following IRF–CRE were due to intervention or to spontaneous/intrinsic recovery following stroke. However, it is reasonable to expect that CRE treatment after a stroke should lead to greater neurological improvement, since the duration after stroke onset is inversely related to neurological recovery (29). The greater improvement in hemiplegia following IRF–CRE sessions and its deterioration in CRE sessions, for which we would expect less spontaneous/intrinsic functional recovery than in the preceding CRE session, suggests that motor functional improvements in hemiplegia were promoted by IRF and that any improvement in hemiplegia would deteriorate in the following CRE session because new neural networks are initially labile and sensitive to disruption before being consolidated into a stable neural network (30). It may be desirable to prolong the duration of IRF to strengthen new neural networks and to maintain motor functional improvement after the disruption of IRF.

An aspect of IRF that may have played a role in promoting motor functional improvement was that IRF combined with CRE might result in an increase in physical activity. However, the effects of increased physical activity with IRF on motor functional improvements in hemiplegic lower limbs are likely negligible: (i) total physical activity was approximately the same in CRE and IRF–CRE, since subjects had 3–4 hours of physical activity (voluntary training and exercise treatment with a physiotherapist or physician) each day in the training room regardless of whether they were in a CRE or IRF–CRE session; and (ii) if the subject had increased physical activity, such an increase would mainly have been for the unaffected limb and trunk and would help to improve walking and ADL rather than motor function of the hemiplegic lower limb. The muscle activity of a hemiplegic lower limb recruited in physical activity seems to be insufficient to improve the isolation of synergy for 2 weeks, since almost none of the subjects could move their lower limbs in their maximally isolated pattern from synergy without facilitation. However, as seen with functional improvements in hemiplegic upper limbs by constraint-induced movement therapy (7), the increase in effort to realize the directed movement of lower limbs may be responsible for the functional improvements in the IRF–CRE session. Although, it is difficult to determine the relative contributions of the repetition of elicited movement by facilitation techniques and the increase in effort to realize directed movements since there were too few subjects to study these 2 effects separately.

With regard to the difference in improvement of walking velocity between IRF–CRE and CRE sessions, there was only a slight difference in the cumulative decrease in the time required to walk 10 metres between the 2 IRF–CRE and 2 CRE sessions. In hemiplegic patients who have recently recovered walking with walking aids, functional improvement of the hemiplegic lower limbs may not directly contribute to an improvement in walking velocity because walking velocity may improve due to an improvement in standing balance due to muscle strengthening on the unaffected side rather than to an improvement in the swing and stance of the affected lower limb.

Our finding suggests that the improvement in the voluntary movement of hemiplegic lower limbs with IRF depends on the nature of the exercise therapy (repetitive elicited voluntary movement and execution of identical movement).

Further research using a randomized control study is needed to better define the effect of intensive repetition of voluntary movement elicited by facilitation techniques on motor functional recovery in hemiplegia, and to optimize the physiotherapeutic approach in stroke rehabilitation.

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