EVALUATION OF MOTOR RECOVERY WITH STROKE IN CHRONIC STATE DEMONSTRATED ELECTROMYOGRAPHY, fMRI, AND DTI

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ABSTRACT
The aim of this study was to evaluate the motor recoveries in 3 chronic hemiparetic patients with Fugl-Meyer assessment (FMA), modified Ashworth scale (MAS), manual muscle test (MMT) scores, EMG characteristics, cortical activation and white matter changes before and after the training program with a symmetrical upper-limb motion trainer training. The training was performed at 1 hr/day, 5 days/week during 6 weeks. Electromyographic activities of the affected hand were recorded during isometric wrist flexion/extension movements. In all patients, FMA and MMT scores except MAS were significantly improved after the 6-week training. Delay in onset/offset of muscle contraction significantly decreased in the affected wrist during the training. The co-contraction ratio of flexor/extensor muscles decreased significantly after the training. We compared cortical activations in two different tasks before and after the training program. Functional magnetic resonance imaging (fMRI) studies in unilateral wrist movement showed that cortical activations decreased in ipsilateral SMC but increased in contralateral SMC and ipsilateral cerebellum. In bilateral wrist movements, bilateral SMC, PMA, SMA and cerebellum showed cortical reorganizations. Diffusion tensor imaging (DTI) results also showed that fractional anisotropy (FA) significantly increased after the training. It seemed that the cortical reorganization was induced by the 6-week training using the symmetrical upper limb motion trainer.

KEY WORDS
Stroke, motor recovery, functional resonance imaging, electromyogram, repetitive-bilateral exercise, and diffusion tensor imaging,

1. Introduction
Current upper limb rehabilitation trainings require enormous efforts of physical therapists, and thus result in high costs and low efficiency for the treatment. Therefore, upper limb training systems have been developed for clinical applications [1,2]. Lum et al. [1] presented robot-assisted mirror image movement exercises in daily repetitive training and compared the results with those by conventional physical therapies. They reported that mirror image movement exercises improve strength and reaching kinematics in the arm of chronic hemiparetic subjects for a 2-month period. Fasoli et al. [2] also demonstrated that the robotic therapy could complement other treatment approaches in persons with moderate to severe chronic impairments by measuring the modified Ashworth scale (MAS), Fugl-Meyer assessment (FMA) and motor status scale (MSS) scores [3] of the upper extremity. Whitall et al. [4] reported that 6 weeks of bilateral exercises with a bilateral arm trainer improved the functional motor performance such as isometric strength and the range of motion of the affected upper extremity. In order to expand treatment strategies, the nature of hemiparesis and its relationship to clinical outcome must be further elucidated using quantifiable methods. Hammond et al. [5] demonstrated significant delays in onset and offset time of muscle contraction in hemiparetic stroke subjects. Fabrizio et al. [6] reported significant differences in EMG interference pattern with abnormal co-contractions of agonist and antagonist muscles.

With the recent development in functional neuroimaging modalities such as functional magnetic resonance imaging (fMRI), positron emission tomography (PET) and transcranial magnetic simulation (TMS), several studies have reported the cortical reorganization induced by physical interventions in hemiplegic patients [7]. Functional imaging and electrophysiologic brain mapping techniques have provided substantial insights.
into the adaptive changes of cerebral networks associated with the recovery from brain damages. Furthermore, the cerebral reorganization of both motor and sensory structures occurs in parallel with the improvement of the upper extremity motor function [8]. However, few studies discussed the cerebellar reorganization after motor recovery [9].

Diffusion tensor imaging (DTI) is a relatively new MRI technique, allowing the orientation and the integrity of the white matter tracts to be determined by virtue of its ability to image water diffusion characteristics [10]. In normal white matter, water molecules move relative freely in the direction parallel to the nerve fiber tract, but their movements are restricted across the tracts, which cause the diffusion anisotropy (DA) of the white matter. In MR diffusion, fractional anisotropy (FA), relative anisotropy (RA), the volume ratio (VR), and lattice index (LI) are commonly used to characterize the DA of a tissue [11]. Among them, FA is most widely referred as an anisotropic index. DTI can provide a quantitative measure of DA, and thus it can be used to obtain quantitative information about the microstructural integrity of the white matter tracts [12]. Since the introduction of DTI, several studies have shown that DA impairment may be correlated with motor dysfunction in stroke patients [13].

The purpose of the present study was to evaluate motor recoveries in chronic hemiparetic patients before and after the 6-week training with the clinical motor impairment and the physical disability, as measured by FMA, MAS, manual muscle test (MMT) scores, EMG characteristics, cortical activation changes using fMRI and white matter changes using DTI.

2. Materials and methods

2.1 Symmetrical upper-limb motion trainer

A symmetrical upper limb motion trainer was made of MC Nylon suitable for MR environments [14]. Both handles of the trainer were connected to two serial spur gears. The system provides both handles with symmetrical motions such as forearm pronation/supination or wrist flexion/extension. Therefore, the affected side can be passively controlled with the same movement according to the active motion of the unaffected side. Subject’s hands were held in place by Velcro straps for the training.

2.2 Training Program

Totally eight subjects participated in this study. As a control group, five of them were right-handed healthy male subjects (age: 34±5, ranging 24–38 years) without any history of neurological or psychiatric disease. Other three were hemiparetic patients (age: 42.0±6.2 years) in chronic state, ≥ 20 months elapsed since hemiparesis; with no severe spasticity (MAS<3) or tremor on affected upper extremity; and no serious cognitive problems, aphasia, attention deficits, or visual neglect. Two patients were left hemiparetic and the other right hemiparetic (Table 1). All patients received the training at 1hr/day, 5 days/week during 6 weeks.

<table>
<thead>
<tr>
<th>Name</th>
<th>Age /sex</th>
<th>Lesion</th>
<th>Time since paresis (months)</th>
</tr>
</thead>
<tbody>
<tr>
<td>KSH</td>
<td>44/M</td>
<td>ICH in Rt. thalamus, BG, IVH</td>
<td>38</td>
</tr>
<tr>
<td>YBJ</td>
<td>49/M</td>
<td>ICH in Lt. thalamus BG, IVH</td>
<td>24</td>
</tr>
<tr>
<td>JYJ</td>
<td>33/M</td>
<td>IVH in Lt. thalamus</td>
<td>58</td>
</tr>
</tbody>
</table>

2.3 Motor Impairment and Disability Testing

FMA of the upper extremity function examines the Presence of synergistic and isolated movement patterns and grasp. Cumulative scores approaching 60 or more for the upper extremity indicate a mild involvement, while scores <20 indicate a severe disability. The muscle tone of the wrist was also evaluated by MAS, ranging from 0 to 5, where 0 represents the normal tone and 5 indicates a severe spasticity. Muscle strength of shoulder, elbow, forearm, wrist and finger were evaluated using MMT, classified into six grades by manual testing: Grade 5 (normal), Grade 4 (good), Grade 3 (fair), Grade 2 (poor), Grade 1 (trace) and Grade 0 (no contraction). During the 6-week training, FMA, MAS and MMT scores were measured every two weeks.

2.4 Electromyography (EMG) Measurements

Surface EMGs were recorded from the flexor carpi radialis (FCR) and the extensor carpi radialis (ECR) muscles. Active electrodes were placed over the muscle belly and the reference electrode over the muscle tendon. During the experiment, the subject’s arm was placed on an apparatus that stabilized the wrist in a neutral position. Each subject was instructed to contract or relax his wrist flexor or extensor in response to an audible beep. For wrist flexion, Each subject was asked to respond to audible beeps consisting of five trials of 3s wrist flexion or extension. All trials were performed in a balanced random order to prevent the subject’s anticipation. EMG signals were band-pass filtered (10-1000Hz) and full-wave rectified. The baseline of the EMG signal was defined as the average activation level for 3 seconds prior to muscle contraction and maintained the above baseline at least during 25 milliseconds. Then, the onset was defined when the rectified signals first exceeded the baseline plus two standard deviations.

In addition, the co-contraction ratio of flexor and extensor muscles was quantified during isometric wrist flexion/extension. Since the muscle force is almost proportional to the integrated EMG (IEMG) [15], we first measured muscle activations in agonist and antagonist during wrist movements.

\[
EMG_n = \frac{EMG_n}{EMG_{n\_rest}}
\]
where $EMG_\alpha$ represents a normalized value of EMG signals during wrist movements. $EMG_m$ indicates muscle activations during wrist movements; and $EMG_{m,\text{rest}}$ indicates a value of $EMG_m$ measured during relaxation.

$$IEMG = \sum_{n=0}^{N} \left[EMG_{n}\alpha\right]\Delta t$$

(2)

where $N$ indicates the number of sampled data in experimental trials and $\Delta t$ is a wrist contraction time.

$$Co-\text{contraction ratio} = \frac{IEMG_{n,\text{ANTA}}^{\alpha\text{GO}}}{IEMG_{n,m}^{\alpha\text{GO}}}$$

(3)

where $IEMG_{n,m}^{\alpha\text{GO}}$ indicates a IEMG of agonist and $IEMG_{n,\text{ANTA}}^{\alpha\text{GO}}$ is a IEMG of antagonist during wrist movements.

For the statistical analysis, one-way repeated ANOVA was used to compare pre-training and post-training (at 6 weeks of training). Spearman’s correlation coefficients describing the relationship between EMG parameters and functional measures were generated. We selected to use the nonparametric test of association in view of the ordinal nature of FMA. An alpha level of <0.05 was used as the level of significance. Representative scatter diagrams relating EMG parameters and clinical measures were generated. All statistical analyses were performed using SPSS 10.0 (SPSS, Chicago, USA).

### 2.5 Functional Magnetic Resonance Image (fMRI)

Before and after the 6-week training program, the blood oxygen level dependent (BOLD) fMRI measurements employing the echo planar imaging (EPI) technique (TR/TE/\(\alpha\)=1900/40/90°, FOV=240mm, matrix size=64×64 and slice thickness=5mm), were performed using a 3T MR scanner (GE Medical System, Milwaukee, USA) with a head coil. A T2-weighted anatomical volumetric images (FSE, TR/TE/\(\alpha\)=4500/104/90°, FOV=240mm, matrix size=256×256 and slice thickness =5mm) were obtained.

Echo-planar images were realigned to the first image of each time series to remove residual head movements. Images were then resliced into the standard anatomic space defined by the atlas of Talairach and Tournoux [16]. The images were then soothed with a 8mm isotropic Gaussian kernel.

For the motor task paradigm, wrist flexion/extension movements were repeated using the nonferritic device inside the magnet in cycles of 20s rest and 20s task. During fMRI experiments, two motor tasks were assigned to every subject: Task 1 was an active wrist movement only on the unaffected side and Task 2 was the passive wrist movement of the affected hand driven by an active wrist movement of the unaffected side. To analyze fMRI data, SPM99 software (Welcome department of Cognitive Neurology, London, UK) was used. Regions of interest were selected as the primary sensorimotor cortex (SMC), the premotor area (PMA), the supplementary motor area (SMA) and cerebellum (SRB), since these areas has been reported to have neuroplastic recovery potential [8]. Significance of the activation between the rest and the task was threshold at $p<0.001$, uncorrected.

### 2.6 Diffusion tensor imaging (DTI)

DTI was performed before and after the 6-week training program. For the anatomic image, conventional T2-weighted images were acquired, and a single shot spin echo planar imaging DTI sequence was used to produce the diffusion tensor images. For diffusion tensor imaging, 30 contiguous axial images were acquired at the internal capsule level and the imaging parameters were: TR/TE/NEX=12000ms/93 ms/1, slice thickness= 4 mm, matrix= 256×256, FOV= 250× 250mm² and b=1000 s/mm². Fractional anisotropy (FA) maps were obtained by using the DTI analyzing DtiStudio 2.03 (Radiology Department, Johns Hopkins University, MD, USA). ROI were drawn in the posterior limb of internal capsule (IC) damaged by hemorrhage in the white matter on the FA maps (Fig. 1).

The posterior limb was identified by its characteristic shape which forms a narrow strip between the thalamus and the putamen and globus pallidus. In every case, a section was selected in which the lesion appear most side before and after 6 week motor training. The correlation between motor recovery of the affected hand and the ratio of FAs of the affected side and the contralateral normal side was investigated. Spearman’s correlation coefficients describing the bi-variate relationship between FMA and FA ratio were generated. An alpha level of <0.05 was used as the level of significance.

### 3. Results

#### 3.1 Upper Extremity Hand Function Tests

Table 2 shows changes in motor function such as FMA, MAS, and MMT during the 6-week training. In all three patients, FMA (range: 0-66) of the affected hands were significantly improved after the 6-week training program.
(p<0.05). MAS (range: 0-5) of the affected wrist spasticity did not change considerably. MMT scores (range: 0-5) of the affected shoulder, forearm, wrist and finger joints significantly increased during the training (p<0.05). However, muscle strength of the elbow did not change significantly.

### 3.2 Onset/offset delays and co-contraction ratio

Table 3 shows onset/offset delays and co-contraction ratio for wrist flexion/extension movements during the 6-week training. Before the training, onset/offset delays on the affected side were significantly larger than those on the unaffected or the control group. It should be also noted that the co-contraction ratio of muscle contraction on the affected side was significantly larger.

As shown in Table 3, after the 6-week training, the unaffected hands as well as the control group did not show significant changes in onset/offset delays and co-contraction ratio for wrist flexion/extension. However, affected hands showed significantly decreased onset/offset delays in muscle contraction after the 6-week training in both wrist flexion and extension (p<0.05). Co-contraction ratio of flexor and extensor muscles also significantly decreased after the 6-week of training (p<0.05).

Spearman’s correlation coefficients were derived, relating EMG parameters from wrist flexion and extension of the affected hand to FMA scores. **Onset/offset delays in muscle contraction** correlated well with FMA scores, except for offset delay in wrist flexion. In addition, the co-contraction ratio in wrist movements versus FMA scores correlated well with FMA scores.

### 3.3 Cortical Activations

In control group, activations in primary contralateral SMC, SMA and ipsilateral CRB were observed in Task 1, with only dominant wrist movement. On the other hand, in Task 2, the passive wrist movement of the non-dominant hand by the active wrist movement of the dominant hand, activations in primary bilateral SMC, PMA, SMA and CRB were observed.

Fig. 2 shows cortical activations for both tasks before and after the 6-week training in the patient group. From fMRI results with Task 1, a cortical activation in the contralateral of the affected side was observed after the training. The ipsilateral SMC activation disappeared in KSH and YBJ. In KSH, the contralateral CRB activation disappeared. It is noted that activations in the contralateral SMC for all patients' unaffected wrist had disappeared and then increased after training. In fMRI results with Task 1, a cortical activation in the contralateral (affected) side was observed after the training. The ipsilateral (unaffected) SMC activation disappeared in KSH and YBJ. In KSH, the contralateral (affected) CRB activation disappeared.

However, Task 2 showed that the contralateral PMA of the unaffected wrist and the bilateral SMA were newly

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**Table 2. Changes in clinical scores of FMA, MAS and MMT on the affected hand of 3 chronic hemiparetic patients before, 2, 4, and 6 weeks of training using symmetrical upper limb motion trainer**

<table>
<thead>
<tr>
<th>No/Name</th>
<th>FMA</th>
<th>MAS (wrist)</th>
<th>MAS (shoulder)</th>
<th>MMT (elbow)</th>
<th>MMT (forearm)</th>
<th>MMT (wrist)</th>
<th>MMT (finger)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/KSH</td>
<td>25-29-33-34</td>
<td>0-2-4-6 (w.)</td>
<td>0-2-4-6 (w.)</td>
<td>0-2-4-6 (w.)</td>
<td>0-2-4-6 (w.)</td>
<td>0-2-4-6 (w.)</td>
<td>0-2-4-6 (w.)</td>
</tr>
<tr>
<td>2/YBJ</td>
<td>20-25-27-32</td>
<td>0-2-4-6 (w.)</td>
<td>0-2-4-6 (w.)</td>
<td>0-2-4-6 (w.)</td>
<td>0-2-4-6 (w.)</td>
<td>0-2-4-6 (w.)</td>
<td>0-2-4-6 (w.)</td>
</tr>
<tr>
<td>3/JYJ</td>
<td>35-49-54-56</td>
<td>0-2-4-6 (w.)</td>
<td>0-2-4-6 (w.)</td>
<td>0-2-4-6 (w.)</td>
<td>0-2-4-6 (w.)</td>
<td>0-2-4-6 (w.)</td>
<td>0-2-4-6 (w.)</td>
</tr>
<tr>
<td>Mean</td>
<td>27.6-34.3-38.0-40.6</td>
<td>1.3-1.3-1.3-1.3</td>
<td>3.3-3.7-3.3-3.7</td>
<td>3.6-3.6-3.6-3.6</td>
<td>3.6-3.6-3.6-3.6</td>
<td>2.3-2.3-2.3-2.3</td>
<td>1.6-2.0-1.6-2.0</td>
</tr>
</tbody>
</table>

w.: week, FMA: Fugl-Meyer Assessment, MAS: modified Ashworth scale, MMT: manual muscle test

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**Table 3. Changes in EMG Parameters before, 2, 4, and 6 weeks of training**

<table>
<thead>
<tr>
<th>Side</th>
<th>Wrist flexion 0-2-4-6 (weeks)</th>
<th>Wrist extension 0-2-4-6 (weeks)</th>
<th>Co-contraction ratio 0-2-4-6 (weeks)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Delay_on (s)</td>
<td>Delay_off (s)</td>
<td>Delay_on (s)</td>
</tr>
<tr>
<td>Controls</td>
<td>(0.17)</td>
<td>(0.31)</td>
<td>(0.22)</td>
</tr>
<tr>
<td>Unaffected</td>
<td>(0.30-0.34)</td>
<td>(0.64-0.51)</td>
<td>(0.34-0.32)</td>
</tr>
<tr>
<td>KSH</td>
<td>0.32-0.37</td>
<td>0.52-0.46</td>
<td>0.42-0.30</td>
</tr>
<tr>
<td>YBJ</td>
<td>0.61-0.41</td>
<td>0.71-0.64</td>
<td>0.78-0.50</td>
</tr>
<tr>
<td>JYJ</td>
<td>0.37-0.33</td>
<td>0.60-0.58</td>
<td>0.44-0.40</td>
</tr>
<tr>
<td>Affected</td>
<td>(0.76-0.73)</td>
<td>(1.80-1.26)</td>
<td>(1.04-0.74)</td>
</tr>
<tr>
<td>Mean</td>
<td>0.36-0.37</td>
<td>0.92-0.76</td>
<td>0.33-0.32</td>
</tr>
</tbody>
</table>

Delay_on: Onset delay on muscle contraction, Delay_off: Offset delay on muscle contraction
unaffected wrist, bilateral PMA and bilateral SMC were newly activated in KSH whose ipsilateral SMC of the unaffected wrist was the only activated site before training. In JYJ, bilateral SMC, PMA was the only activated before training, bilateral and medial CRB of all patients were activated after the training (Fig. 2). Unlike in Task 1, it is noted that activations in the contralateral SMC for all patients’ unaffected wrist had disappeared and then increased after training.

3.4 Diffusion tensor imaging (DTI)

Table 4 shows FA ratio before and after the training. The FA ratio significantly increased after the training ($p<0.05$). The relationship between FMA and FA ratio of the patients was examined. FAR from the initial DTI did not show a linear correlation with motor impairment. In addition, a significant correlation was found between motor recovery and FA ratio in the posterior limb of IC ($p<0.001$).

<table>
<thead>
<tr>
<th>Name</th>
<th>Before</th>
<th>After</th>
<th>dFMA</th>
</tr>
</thead>
<tbody>
<tr>
<td>KSH</td>
<td>0.61</td>
<td>0.62</td>
<td>9</td>
</tr>
<tr>
<td>YBJ</td>
<td>0.61</td>
<td>0.62</td>
<td>12</td>
</tr>
<tr>
<td>JYJ</td>
<td>0.60</td>
<td>0.62</td>
<td>14</td>
</tr>
<tr>
<td>Mean</td>
<td>0.61</td>
<td>0.62</td>
<td>14</td>
</tr>
<tr>
<td>SD</td>
<td>0.01</td>
<td>0.09</td>
<td>6.24</td>
</tr>
</tbody>
</table>

4. Discussion

In this study, we evaluated the upper limb motor functions, using the temporal EMG characteristics, muscle coactivation, cortical activation patterns and white matter changes in threecromic hemiparetic patients as well as five normal subjects.

The hypothesis of our study was that the repetitive, symmetric movement training improves motor functions in chronic hemiparetic patients. Both arms are strongly linked as a coordinated unit in the brain, when bimanual movements are initiated simultaneously [17]. It is also well known that even if one arm or hand is activated with a moderate force, this force can produce motor overflow on the other such that both arms are engaged in the same or opposite muscle contractions irrelevant to force levels [18].

In this study, after the 6-week training program using the symmetrical upper limb motion trainer, significant improvements were observed on FMA and MMT tests.

with respect to the functional ability and the muscle strength. Most quantitative EMG studies performed on impaired limbs of hemiparetic stroke patients have dealt with temporal analyses of EMG patterns during arm movements [5]. Many researchers found significant onset delays of muscle contraction in the hemiparetic upper limb. The delay in muscle contraction can be extended when the decrease in inhibitory control of central nervous system (CNS) after stroke or brain injury causes muscle stiffness or excessive co-contraction of the antagonist muscle. It may be also extended when the function of intact reticulospinal tract is activated with the dysfunction of corticospinal tract or when the cortical reorganization is developed [19]. The co-activation of agonist and antagonist muscles is an important component of motor control in normal individuals. It participates in the regulation of joint stiffness and postural stability [5]. As regulated by a feed forward mechanism, it is modulated according to task requirements. An abnormal co-activation pattern, consisting of massive and synergistic activation of many muscles, has been reported on the affected side of hemiparetic patients during movement [6].

In the present study, we observed that a co-contraction ratio, which was defined by the ratio between agonist and antagonist using IEMG, significantly decreased after the 6-week training. In this study, we found a statistical relationship between the degree of the onset, offset delay and co-contraction ratio of muscle contraction and clinical measures of motor impairment and physical disability. Activities of daily living require prompt and coordinated repetitive initiation and termination of muscle contractions. Many stroke survivors achieve the hand closure by isolated movements or by volitionally activating a flexor synergy pattern. The correlation between these neural deficits and clinical measures may reflect a mechanistic or cause-and-effect relationship. Dewald et al. [20] demonstrated a similar statistical relationship between muscle co-activation patterns of synergistic muscles in the paretic upper limb and FMA scores.
Few studies have used functional neuroimaging to support the notion that, a task-oriented training can induce cortical reorganization in stroke patients [7]. They demonstrated that functional recoveries by physical interventions were associated with the increased ratio of contralateral SMC activity during the movement of the affected hand. The secondary motor, SMA and PMA may be activated by the mere imagination of complex movements [8]. Several studies have been conducted to find pathophysiological mechanism of mirror movements [21]. Kim et al. [22] reported that bilateral SMC was activated during mirror movements of finger in all post-stroke patients in their fMRI experiments. However, in the present study using the symmetrical upper limb motion trainer, the contralateral SMC of all patients' unaffected wrist was not activated before the training and then activated after the training.

It is well known that the corticospinal tract is essentially required for the fine motor activity of the hand, and that motor recovery of the hand is correlated with the amount of the functional corticospinal tract [23]. The FA is a popular index to quantify degree of DA, and has been used as an indicator of white matter integrity at the microstructural level [10]. In this study, the FA in the affected side was significantly smaller than that in the unaffected side. Several investigators have tried to demonstrate that the microstructural abnormalities, such as the degree of DA impairment, reflect motor dysfunction at the time of DA evaluation in stroke patients [24]. More recently, the role of DTI as a potential marker to predict motor outcome in stroke patients has been suggested [25].

Watanabe et al. [26] demonstrated that a three dimensional axonograph constructed using the DTI method in the early stages of stroke may be useful for predicting the prognosis of motor function. The FA of the unaffected side in patients was significantly smaller than that of control subjects. Reasons for this phenomenon might be the inter-hemispheric influence of the motor system or the immobilization effect. Many studies have demonstrated that the affected motor cortex can affect the unaffected contralateral motor cortex via transcallosal pathway or by some other pathways [27]. Other reports have demonstrated that the long-term forced use of a hand can increase the DA of white matter [28].

Even though the present study has a limitation due to the small number of subjects, it would be very valuable to demonstrate motor recoveries in chronic stroke patients using EMG, fMRI and DTI. Further studies on the changes in the cerebrum, cerebellum and white tract by reorganization and motor pathway would be required to clarify motor recovery with more clinical long-term analysis.

5. Conclusion

This study showed that a repetitive, symmetric movement training can improve upper limb motor function and ability in all three patients with chronic hemiparesis. In this study, the clinical motor impairment and physical disability, as measured by the FMA, MMT scores increased significantly. Affected hands showed significantly decreased onset/offset delays in muscle contraction after the 6-week training. Co-contraction ratio of flexor and extensor muscles also significantly decreased after the 6-week of training. Main changes in cortical activation were a decrease in ipsilateral SMC, an increase in contralateral SMC and ipsilateral CRB. Mirror exercises with passive movements of the affected side due to the active movements of the healthy side clearly showed cortical reorganization in bilateral SMC, PMA, SMA and CRB. DTI studies also demonstrated that FA ratio significantly increased after the training and a significant correlation was found between the motor recovery and FA ratio in the posterior limb of IC. It seemed that the cortical reorganization was induced by the 6-week training using the symmetrical upper limb motion trainer. Understanding the neural mechanisms of motor recovery may be useful to improve the current therapeutic strategies of motor rehabilitation.

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References


