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# Changes in frequency properties of electroencephalograph and electromyography in motor learning process

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**Changes in frequency properties of electroencephalograph and electromyography in motor learning process**

The purpose of this study was to investigate the modifications of motor performance and changes in electrophysiological properties such as electroencephalogram (EEG) and electromyography (EMG). The subjects consisted of six healthy males aged 18 to 24 years (mean =21.8 years). The task of motor learning was maximum reciprocal tapping of the Ⅳ and Ⅴ finger in the non-dominant hand. Practices were executed 5 days per week for 4 weeks. Parameters of analysis were rate of tapping, median power frequency properties in EEG and EMG during 10 seconds.

The results showed significant increases in the mean rate of tapping and median power frequencies in EEG. Correlation between rate of tapping and median power frequency of EEG on the motor cortex showed a gradual increase with each week. There was no significant correlation between rate of tapping and median power frequency properties of EMG.

It is suggested that an increase of neural activities in the cortex may correlate with the evolution of motor learning.

**Key Words :**
Motor learning（運動学習）, EEG（脳波）, EMG（筋電図）

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## 1. Introduction

In physical therapy, some therapeutic inputs such as verbal orders, demonstrations, manual assistance and mechanical assistance are applied to the patients in order to improve the performance of motor control.

The series of processes concerned with relative permanent changes of motor performance caused by these repetitive therapeutic inputs is defined as motor learning[1)2)].

The conceptual models of motor learning theory, such as closed loop theory[3)], schema theory[4)], impulse variability theory[5)] and knowledge of results (KR) [6)7)] have been previously discussed.

Experimental approaches based on the above motor learning theories have been developed from the fields of psychology, physical education, neuroscience, bio-information engineering and others[1)].

In previous experimental studies, analyses of motor learning have been executed based on the change of performance criteria such as speed, accuracy in movement, as well as analyses based on the changes of electrophysiological properties such as EEG and EMG[6)].

In physical therapy, both analyses of performance and electrophysiological properties are important in order to prove the scientific evidence related to acquisition of motor skill by therapeutic exercise.

However there are only a few studies which attempt to explain the neuromuscular changes which accompany skilled motor learning in physical therapy.

With regards to electrophysiological studies related to motor control or motor learning, Murthy and Fets[8)] indicated that the band ratio of the $\beta$ wave of electroencephalogram was observed during tasks requiring fine finger movements and focused attention in monkey motor cortical cells. Karni et al.[9)] reported that expansion of activated regions in primary motor cortex during motor skill learning observed by functional magnetic resonance image (f-MRI) may be caused by the organization of synapse network related to the evolution of motor skill learning.

Concerning the changes of cortical activity when executing learned motor sequences, Lang et al.[10)] reported that in a learned sequence of four movements (flex index finger, extend hand, extend index finger, flex hand), large negative DC potentials were recorded in positions located above the mesial fronto-central cortex (Cz) and sensorimotor hand areas of either hemisphere (C 3 and C 4) in the beginning of each period. Furthermore, DC potentials were absent in Cz and the end of the period of execution.

On the other hand, an electromyographical study conducted by Sadoyama et al. 11) examined the modification of auricle muscles using EMG to evaluate the effect of motor learning quantitatively. Since the results indicated that the acquisition process of auricle movement was effectively shown, as demonstrated by the gradual increase in mean amplitude of the EMGs of auricle muscles, they suggested that EMG signal processing method has wider application in the field of neuromuscular rehabilitation and sports.

Vallbo et al.[12] investigated the human muscle spindle response in a motor learning task by using microneurographic technique, and they concluded that focusing attention on the kinaesthetic input during imposed movement was not associated with a consistent increase of fusimotor drive.

Although the above previous studies reported on the elecrophysiological evidences based on the analysis of EEG or EMG in motor control or motor learning process, changes in the frequency properties of EEG or EMG in motor learning processes have not been discussed. Furthermore, correlation between evolution of motor performance and changes in electrophysiological properties have not been discussed.

Fets et al [13]. reported that a cortical motor neuron projects alpha motoneuron and it regulates the generation of muscle force.

Consequently, it appears that changes of frequency properties in EEG or EMG may reflect modification in cortical neuron activity and myoelectrical activity by motor learning. These quantitative analyses of motor learning may be necessary in order to clarify the effects of therapeutic exercises in physical therapy .

The purpose of this study was to investigate the effect of motor learning based on the modification of motor performance and changes in frequency properties in EEG and EMG.

## 2. Subjects

Subjects were six healthy males aged 18 to 24 years (mean 21.8 years) who had no previous experiences about continuous skill motor learning such as playing the piano. Informed consent to the experiment was taken from all subjects. Subjects were all right handed.

## 3. Methods

1) Task of Motor Learning

The maximal reciprocal finger tapping of Ⅳ and Ⅴ finger in the non-dominant hand with maximum velocity was selected as a motor learning task. The subjects were instructed to execute maximum reciprocal finger tapping in Ⅳ and Ⅴ finger in the non-dominant hand, placing their left palms on the desk and observing their own movements.

The task was selected because it is not used in daily activity, and improvements of motor skill by practice can be expected.

2) procedure

During practice, subjects were seated on a chair, with their back supported, and only their left hand was placed on the desk.

The task consisted of a block of 50 trials per day, and one trial includes reciprocal finger tapping of left Ⅳ and Ⅴ finger for 10 seconds with maximal velocity and a rest period of 10 seconds. The practice was executed for 5 days (from Monday to Friday) per week for 4 weeks.

The whole sequence of practice for a subject was as follows :

1 block/day × 5 days × 4 weeks = 1,000 trials.

The practice of motor learning was limited to only the practice time in a day to prevent the bias induced by over training performed by the subjects during their private time.

3 ) Measurement

The contents of measurement consisted of the rate of reciprocal tapping in Ⅳ and Ⅴ finger, electroencephalogram, and electromyography in left finger extensor and flexor during 10 seconds. The trigger sound to start and stop the tapping was generated by a phono-stimulator (Sanei, 3 G 22) with 10-second intervals. Measurements were carried out once per week. The data were corrected from 5 th to 7 th trials during a block in a day per week.

Measurements were executed in a shielded room to prevent noise.

The contact pressure of tapping by Ⅳ and Ⅴ fingers was measured by using touch sensor equipment (ME, specially made) on the desk. The touch sensor equipment was made by an aluminum box and two touch sensors, and touch sensors were adjusted to position the Ⅳ and Ⅴ finger pulp within the box. The touch sensor signals were amplified by a DC amplifier (Unipulse, Digital Indicator F 430), and were stored to a data recorder (Shinko, RCD-728).

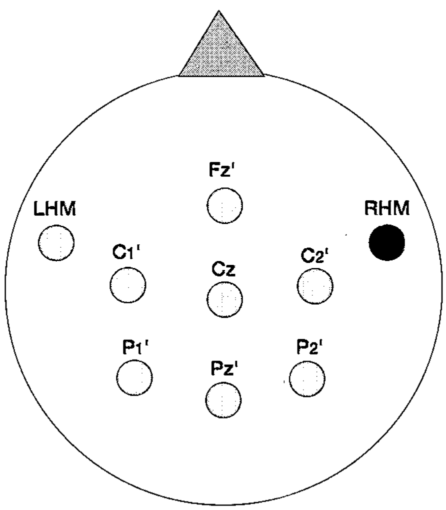


Fig. 1 Placement of Electrodes in EEG
RHM was focused in this investigation.

Recordings of EEG signals during tapping were made by an EEG machine (NEC Sanei, MK－930705) with 8 silver-silver chloride cup electrodes. The electrodes were placed over the scalp at Fz', C 1', Cz, C 2', RHM, P 1', Pz', P 2' based on the movement related cortical potentials (MRCP) using a conductive electrode gel (Fig. 1). The electro-oculogram (EOG) was recorded from an electrode placed 1.5 cm below the right outer canthus in order to check the blinking. The subjects were required to keep their eyes opened during each trial in order to prevent artifacts caused by blinking.

Two common reference electrodes were placed on the earlobe.

EMG signals of left Extensor Digitorum Communis and Flexor Digitorum Sublimis during reciprocal finger tapping were detected by a telemetric EMG machine (NEC San-Ei, Multitelemeter 511) with surface electrodes. Before placing the silver-silver chloride disposal type electrode, the skin was first prepared with an abrasive alcohol prepping solution, and electrode impedance was always below 2 kΩ. A pair of electrodes were placed in the center of the muscle belly, parallel to the direction of muscle fibers.

Detected EMG signals were stored on a data recorder together with tapping signals and EEG signals.

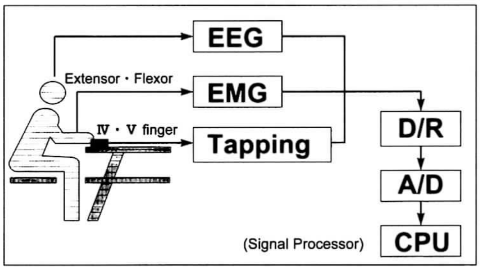


Fig. 2 Block Diagram of Experiment

4 ) Data Analysis

The analog data of tapping signals, EEG signals and EMG signals were converted to digital signals by an A/D converter with 1 kHz sampling frequency from the data recorder.

Signal processing was executed on a personal computer (NEC, PC-9821 Xp) with a software for processing of bio-information signals (Kissei Comtec, BIMUTAS-E, ver. 2.11) (Fig. 2, Fig. 3).

Digital filters were used to reduce the noise in each signals using BIMUTAS-E. The tapping signals were filtered by low pass filter below 10 Hz. EEG signals were filtered by band-pass filter ranged from 0.5 Hz to 30 Hz. EMG signals were filtered by band-pass filter ranged from 10 Hz to 250 Hz[14].

Frequency properties of EEG signals and EMG signals were analyzed through Fast Fourier Transform (FFT) with Hanning window function, and median power frequency (MdPF) was calculated using BIMUTAS-E.

Data analyses of maximum tapping, MdPF of EEG and EMG were performed using averaging value of data in 5 th to 7 th trial of subjects in each week.

Among the placement of scalp electrodes, RHM was focused in this study since RHM lies close to right primary motor cortex for finger movement[15].

5 ) Statistical Analysis

To test 4 weeks practice effects on maximum tapping, MdPF of EEG and EMG, Friedman test was performed by using SPSS 6.1 for Windows (SPSS Inc.), because normal distribution was not observed in these

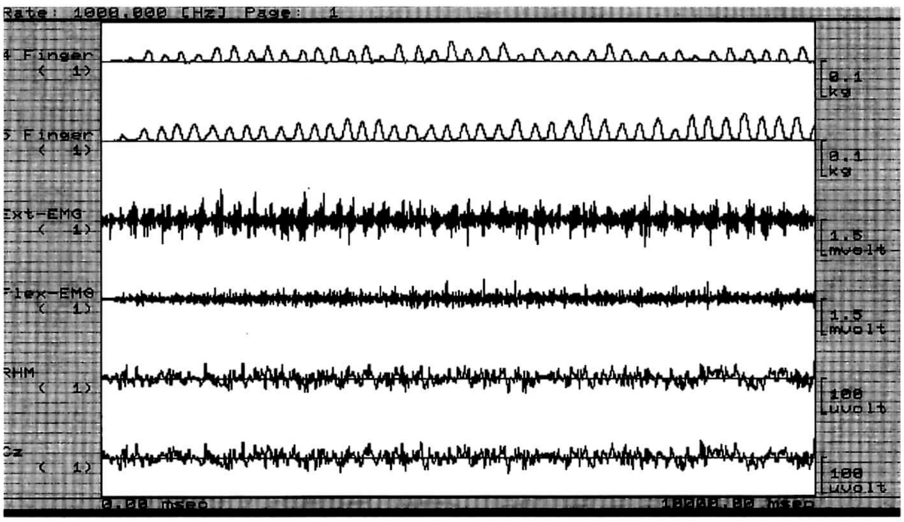


Fig. 3 Raw Data of Reciprocal Finger Tapping

Table 1 Changes of Motor Performance and Electrophysiological Properties

| | 1W | 2W | 3W | 4W |
|---|---|---|---|---|
| Rate of Tapping | 40.1±16.1 | 51.9±15.7 | 56.8±17.6 | 62.8±16.3 |
| Mean MdPF in EEG (ALL) | 9.9± 2.5 | 11.4± 1.9 | 11.7± 1.9 | 12.6± 2.6 |
| Mean MdPF in EEG (RHM) | 9.7± 2.1 | 11.6± 2.0 | 12.8± 2.9 | 12.8± 2.8 |
| Mean MdPF in EMG(Ext.) | 96.8± 5.9 | 101.1± 7.6 | 98.8±11.1 | 98.7± 9.9 |
| Mean MdPF in EMG(Flex.) | 96.9±16.3 | 91.5±14.0 | 85.8±18.0 | 90.0±18.8 |

mean±SD

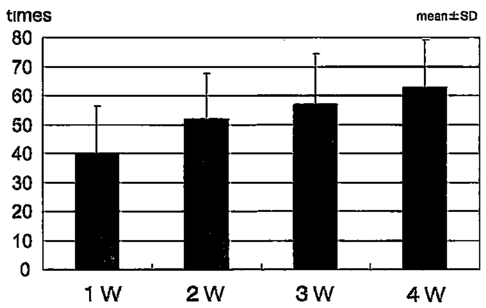


Fig. 4 Modification of Rate of Tapping

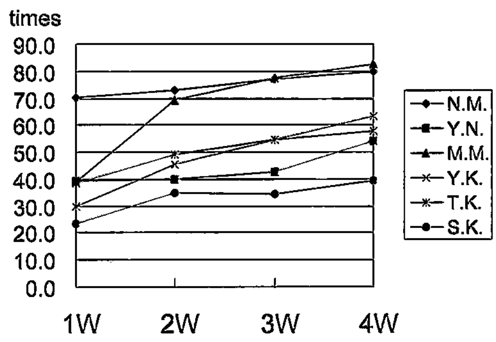


Fig. 5 Individual Difference in Rate of Tapping

data. To test for difference among the 4 weeks, Dunn test was used as a post hoc test. Statistical significance was accepted at less than 0.05

## 4. Results

1) Modification of Motor Performance

The mean number of times in reciprocal tapping of IV and V finger were increased in all subjects every week (Table 1, Fig. 4).

Statistical significance was observed among weeks by Friedman test ($p<0.01$) (Table 2). Dunn post hoc testing indicated significant difference between the 1 st week and 4 th week ($p<0.01$)

Although the mean rate of reciprocal tapping revealed an almost linear increase, individual differences were observed in the learning curve of individual subjects (Fig. 5).

2) Changes in Median Power Frequency Properties in EEG

Since subjects could keep their eyes open during data acquisition, prevention of artifacts by blinking were confirmed by EOG.

Mean value of MdPF on all electrodes in EEG reveals a tendency to increase every week (Table 1, Fig. 6). Friedman test showed significant increase of MdPF on all elec-

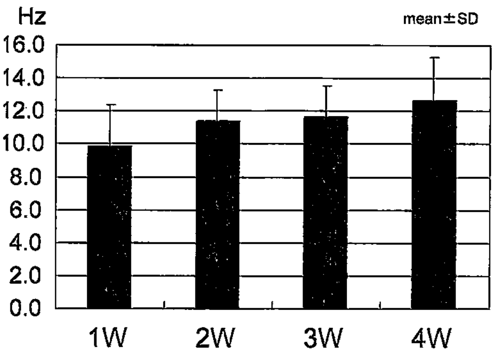


Fig. 6 Changes of Mean MdPF in EPG on ALL Electrodes

trodes in EEG ($p<0.05$) (Table 2). Dunn post hoc testing indicated significant difference between the 1 st week and 4 th week ($p<0.05$)

In the change of MdPF among the placement of electrodes, RHM revealed a steep increase of MdPF compared with other sites (Table 1, Fig. 7).

Friedman test showed significant increase of MdPF on RHM ($p<0.05$) (Table 2, Fig. 8). Dunn post hoc testing indicated significant difference between the 1 st week and 3

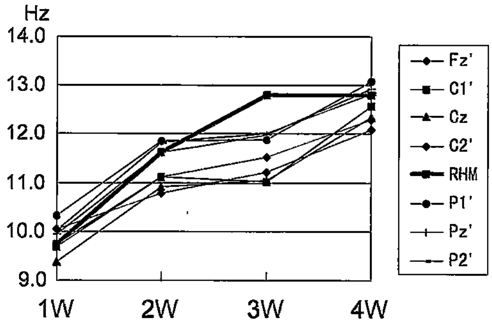


Fig. 7 Changes of Spatial Distribution in EEG on all Electrode

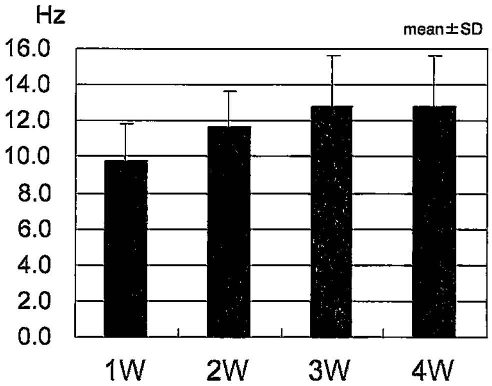


Fig. 8 Changes of Mean MdPF in EEG on RHM

Table 2 Results of Friedman Test

| | source of variation | $\chi r^2$ | k | N | df | P value |
|---|---|---|---|---|---|---|
| 1) Rate of tapping | | | | | | |
| | between conditions | 17.00 | 4 | 6 | 3 | 0.01 |
| | between subjects | 16.00 | 6 | 4 | 5 | 0.001 |
| 2) MdPF in EEG (All) | | | | | | |
| | between conditions | 9.80 | 4 | 6 | 3 | 0.05 |
| | between subjects | 11.29 | 6 | 4 | 5 | 0.05 |
| 3) MdPF in EEG (RHM) | | | | | | |
| | between conditions | 11.00 | 4 | 6 | 3 | 0.05 |
| | between subjects | 14.29 | 6 | 4 | 5 | 0.02 |

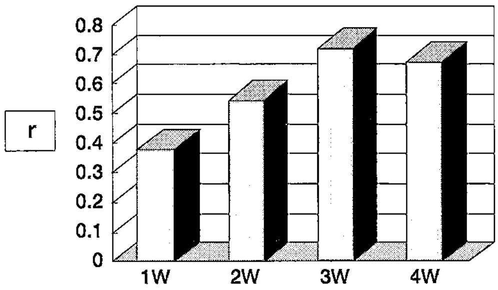


Fig. 9 Changes of Coefficient of Correlation between Rate of Tapping and MdPF of EEG in RHM

rd week ($p<0.05$).

3 ) Changes in Median Power Frequency Properties in EMG

Friedman test indicated no significant change of MdPF in EMG for both extensor and flexor during 4 weeks ($P>0.05$) (Table. 1). MdPF of EMG in finger extensor muscles were higher than flexor muscles at the 2 nd, 3 rd and 4 th weeks. Change of discharge pattern of both EMG was not observed.

4 ) Correlation between motor performance and electrophysiological properties

Correlation coefficient between rate of tapping and median power frequency properties on RHM in EEG were gradually increased every week up to the 3 rd week (Fig. 9).

There were no significant changes between motor performance and EMG signals or between extensor and flexor.

## 5 . Discussion

In the present study, it was demonstrated that motor performance in motor skill learning was improved by daily practices, and MdPF in EEG on all electrodes revealed significant increase every week.

The motor task of present study was selected based on the comments that reciprocal tapping of Ⅳ and Ⅴ finger in non-dominant hand is difficult to train for flute players. However, the motor task in present study does not have great benefit for the subjects. Also, knowledge of results were not informed to the subjects till completion of their practice period.

Nevertheless, motor performance of the maximum reciprocal tapping of Ⅳ and Ⅴ finger in non-dominant hand were improved by practices during 4 weeks, as we expected.

This result indicates that new skilled motor task which has not been experienced previously has the possibility of modification in motor learning.

However, since we did not evaluate the long term effect after completion of practice, it seemed that further study should be continued.

With regards to the phases of motor learning, Fitts[16] classified cognitive phase, associative phase and autonomous phase. Since content of task in the present study was simple reciprocal finger tapping, it seemed that the degree of participation of cognition may be small. But the discrimination between associative phase and autonomous phase in present study may be difficult because we did not check the transfer trials.

The effects of knowledge of results (KR) should also be investigated since it is considered that import, timing and frequency of KR may affect the motor performance[7)17)].

Although Busk and Galbraith[18] pointed

out that skilled movements were not likely to be reflected in the EEG, MdPF of EEG in all electrodes revealed significant increase, accompanied by the improvement of motor performance in present study. In particular, RHM which lies over the primary motor cortex related to left finger movement revealed on acute increase. Furthermore it was noteworthy that the coefficient of correlation between the rate of reciprocal finger tapping and frequency properties of EEG on RHM were increased during motor learning process.

Gliner et al. [19] investigated changes in the EEG power spectrum during repeated performances of the same task to determine whether neurophysiological correlates of attention changed as a function of learning the task. His results indicated that mean alpha frequency increased slightly during the task while delta frequency decreased in electroencephalogram during perceptual-motor learning. He also reported that a decrease of duration in execution and decrease of error in task were observed by motor learning.

Since his report aimed to clarify the influence of attention in perceptual motor learning based on the EEG, it is considered that direct comparison to the present study may be difficult.

Lang et al. [10] studied the changes of cortical activity when executing learned motor sequence, and he concluded that the execution of a learned motor sequence task cannot be associated with a particular size and pattern of cortical activity. Since they did not analyze the frequency property in EEG, it seemed to be necessary to analyze the change of frequency properties in EEG during motor learning process.

As a spatial property of frequency on all electrodes in EEG, EEG on RHM revealed linear increases of median power frequency in motor learning process. This tendency may suggest the increase of neuronal activities in the cortex included RHM.

Tanji and Mushiake[20] reported that primary motor cortex is mostly related to execution of motor task, while neuronal activity in the supplementary motor area exhibits a variety of complex relationship to many different aspects of motor task. Thach[21] reported that there are close relationship between neuronal activity in primary motor cortex and motor parameters such as joint position, force, velocity and acceleration of movement generated by muscle contraction.

From these evidence, it is considered that neuronal activity in primary motor cortex may correlate with evolution of rate of reciprocal finger tapping as a motor learning task in present study, because simple reciprocal finger tapping was used as a motor task in this study. This speculation may be supported by increase of coefficient of correlation between rate of reciprocal finger tapping and median power frequency of EEG on RHM.

It is also suggested that correlation analysis between motor performance and cortical activity seemed to be useful in quantitative evaluation of electrophysiological change in motor learning.

In the present study, EMG of finger extensor revealed dominant activity in late stage of motor learning process. However, there were no significant changes of MdPF in EMG on the finger muscles during motor learning process.

Basmajian[22] reported that properties of EMG activity in motor learning process is selective inhibition of unnecessary muscular activity rather than the activation of additional motor units. He cited evidence that the development of skill is accompanied by progressively more successful repression of undesired contractions and by a gradual increase in the average duration and a decrease in average frequency of potentials in the specific muscle under training.

Payton and Kelley[23] investigated the change of EMG activity in motor learning process. They concluded that prime muscles demonstrated significantly less total electrical activity during skilled movements than during unskilled movements.

From these evidence, dominant change of frequency properties in extensor muscles may suggest inhibition of the activity of flexor muscles. However, since integrated EMG was not calculated in present study, we could not conclude the change of total electrical activity in EMG in motor learning process.

From above findings, it seemed that further electromyographical study in motor learning process should be continued.

Crutchfield[2] indicated that considerable portion of therapy is to teach the clients. It is also described that a large body of knowledge in teaching is based on the motor control theories and motor learning theories. Furthermore he indicated that incorrect model of treatment can lead to inappropriate expectations of the results.

From these valuable information, it is considered that appropriate treatment program for motor learning in physical therapy should be constructed by integration of both the scientific investigation and clinical data in motor learning.

The findings of the present study are limited in that the sample was small and only short term effects were studied. Furthermore, since we did not analyze the ratio in frequency band in EEG, it is considered that analysis of the detailed frequency component of EEG in motor learning is necessary. Further research is necessary to analyze motor learning process in actual patients with motor disorders.

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