Motor Control of Electromyographical Signals with the Biofeedback Training

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Biofeedback method has been applied to the motor control training, of which aim is to keep a fixed constant surface EMG’s signal during the flexor muscle contraction of the upper arm. The biofeedback method with the motor control has objected to make motor response with high sensibility and stability, and to give subjects the biofeedback training (BFT) in order to improve the covert sensory function.

In the experiment, measuring items were as follows: integrated error values between the motor command and the controlled variable of surface EMG (motor performance), the flexor muscle strength of the upper arm during an isometric contraction in the tracking (energy cost), and the spectrum analysis of error values (transfer function). The error spectrum should have been estimated to analyze the gain and the phase in the transfer function of the motor control.

Adding the biofeedback training to the myoreflex control system, following results were obtained: 1) the gain in the motor control system increased efficiently, but the phase had no changes in the tracking after BFT. 2) the flexor muscle strength decreased with the low-cost energy of contraction after BFT. 3) motor performance had been improved with BFT significantly. 4) the covert sensory function might be elevated up to the overt sensory situation in the myoreflex control system.

Key words: Motor Control, EMG, Biofeedback Training

INTRODUCTION

Research methods of the biofeedback training (BFT) has been defined by Miller and Banauzizi (1968), as follows. Man should be able to catch information about his inside signals by the special equipment with the outside high sensibility which has designed to make much more information of physiological responses. The biofeedback method for the physical behavior has been contributed to control these signals of the neuro-muscular motor system consciously by assistance of changing from the external information to the internal one.

From 1930s in the research field of the psychology, there had been published a lot of papers about participates and possibilities of the operant conditioning and the tool conditioning for self-control of motor behavior. As results of these studies (Skinner, 1938 and Mowrer, 1947), many data on the operant conditioning for self-control had been reported. But possibilities of self-control had been denied to be forced superior to the classical conditional reflex. In 1960s, Miller (1969 and 1978) had cleared on the success of the operant, device and tool conditioning for self-control of behavior with the method of Shapping.

Recently, many studies on the biofeedback have been practiced in fields of the pathology and the rehabilitation which have dealt for patients with applicative prescription of the motor behavior. For example, Shapiro and Watanabe (1971) has indicated that there are much unbalance phenomena of biofeedback researches between the fundamental theory and the practical identification, although data of the identification have not shown more in this field of the biofeedback quantitatively. Then, chaotic discussions about definition of the biofeed-
back quantitatively. Then, chaotic discussions about definition of the biofeedback have appeared frequently. In the research of the biofeedback approach, there are two viewpoints. One point is that the biofeedback is considered the operant control conditioning (Fetz & Finochio, 1971 and Miller, 1978) and the other point is that the biofeedback response is considered the voluntary control (Stern & Lewis, 1968, Klinge, 1972 and Schwartz, 1975). Main difference between two viewpoints have been considered what standing point of the feedback function depends on the motor behavior.

In the operant control, the feedback function has been regarded as a kind of the reinforcement by the motor learning, and it has practiced as the function of reduction in the motor driving pain. On the other hand, the feedback function has been regarded as a sort of information or signals from the motor behavior in the case of the voluntary control. The difference between both viewpoints should be shown on the demonstration which the parameter of the time factor was used to estimate physical responses. Then, the motor reinforcement should be given for the motor behavior effect together with the predicting motor response according to the principle of the motor effect. Also the feedback function should be given as one function of the motor control for the next information of the continuous behavior.

About the movement time delay, the reinforcement of the predictive behavior was considered not to be the main factor to decide the motor behavior (Shapiro & Watanabe, 1971). If the feedback had been regarded as a simple information or a signal, the function would have no effects on the motor behavior. Then, the feedback function should be explained as one element of the generated source on the movement control, and the same continuous information should be interpreted as the one component of the transformation control. On understanding about the meaning of the behavior, such functions as timing, phasing, direction, modulation, integration, modification, and grading from the behavior depended upon the feedback information. Functions would be looked forward to be analyzed in the experiment.

Application of the biofeedback method has been used for the medical treatment and the release from the nervous stress in the field of the rehabilitation. Recently, the method has been begun for application to increase the recognizing physical level which has not been perceived in the body physiologically. The generated information in the inside body have been changed to the controlled level in the outside body. For example, inner living signals from the sensory motor system have been used for the motor control as following of the decreasing effect on the blood pressure, of the keeping response on the resting heart rate about 65—70 beats/min., of the generating effect on the slower frequency of EEG, of the holding the constant resting value of GSR, and of the releasing diagnosis from the muscular rigidity, spasm, and pain. Living signals have not been perceived at conscious level in general and been covered with voluntary movements. In the up-to-date application, both voluntary and involuntary signals have been used widely for the motor learning and proficiency, and for the skillful development of physical activities. Recently the unconscious signal has been dealt with the controlled problem of the biofeedback training. Though many application and practice of the biofeedback have been performed, there are a few papers of the academic materials.

The first purpose of this study is to analyze the motor control mechanism to regulate the neuromuscular function by the method of the biofeedback training and to assemble data of the motor learning skillfully in the experiment of keeping EMG's signals with the voluntary contraction. These muscular signals were not detected under the condition of the general consciousness without the special biofeedback device. By the measurement of new equipments, EMG's signals could be detected of oneself in the place of the controlled value. These
signals have been transferred to be controlled and to be utilized as the biofeedback information by the peripheral motor organ; the muscle spindle, the tendon organ, and the joint receptor. By utilizing special biofeedback devices, these signals are possible to be recognized with the information of the outside body and to be changed with the overt signal. In the present study, the new biofeedback device are manufactured and are designed into the biofeedback loop artificially. Then, EMG's signals are shown as the controlled value in this experimental system.

The second purpose is to identify possibilities of the motor control by the biofeedback method in the peripheral motor system quantitatively. Primarily, muscular signals are regulated by the central and superspinal motor cortex (Fig. 1), but in this study, the lower peripheral motor system might play an important role in the motor control on EMG's signals. Identical data of the transfer from the central nervous system to the peripheral one should be sampled as materials of the biofeedback application.

Additionally, this study is an aim to clear up the motor servo system relating the central nervous system and to establish the biofeedback training method in the research of the muscular contraction.

**METHOD**

Fig. 2 shows the experimental system, which has been used under Exp. 1 and Exp. 2. At Exp. 1, the pursuit tracking is practiced in the motor control, while at Exp. 2, the compensatory tracking is applied to this method.

At Exp. 1, surface electrodes are placed on the

![Figure 1](image1.png)

*Figure 1* Motor control scheme of the peripheral motor control system with sensory muscle function

![Figure 2](image2.png)

*Figure 2* Experimental system of the biofeedback training.

Exp. 1: Pursuit tracking control and Exp. 2: Compensatory tracking control
motor point of M. Biceps Brachii. EMG is measured by the bipolar lead and is recorded into the data recorder, and then the signal is rectified by the electric rectify amplifier with the time constant of 0.5 sec. Furthermore, the rectified EMG is transferred to become the command value of DC signal. From the other electric DC source, electric potential 1.0 V is generated externally, of which value is compared with the amplitude of EMG's signals. Both values are applied for subjects to track continuously in the cathode ray oscilloscope (CRO), which is used as the display monitor. On CRO, two kinds of beams are shown as the information of the visual sensory system. At Exp. 2, the muscular tension is used as the command value for the tracking.

The difference between both signals is detected by the equipment of the different AMP and is changed into the sound of the auditory feedback information by the Voltage-Frequency (V-F) converter. The deviation of two beams in CRO and the sound tone for the ear are controlled to be altered in proportion to EMG's signals or muscular strength. Two signals of the visual beam and the auditory sound changes are the same as the information which are transferred from the covert signal in the sensory motor system to the overt one, and are reinforced to be sensible in the motor control.

In the next analysis, the integrated error between the command value and the rectified EMG value are recorded to the practical estimation (arbitrary unit) for the motor control performance in BFT. At the same time, the muscular strength of M. Biceps Brachii is measured with the use of the strain gauge.

Eleven male subjects are selected and are divided into two groups, which are named as the experimental group (EG, 6 males) and the control group (CG, 5 males). At Exp., EG have been trained for 3 days with 50 trials, which are composed of 10 blocks and continued to practice the muscular contraction of 3 levels (high, middle, and low strength) for every 60 sec trial. On the other hand, at Exp. 2, 31 trials were trained at EG, and CG have been also trained with only one level (middle strength) for every 60 sec trial for the same number of days. Experimental proposals are shown in detail on Table 1. The command value of Exp.1 used is the rectified EMG, while that of Exp.2 is the muscular tension.

All experimental data have been recorded in the magnetic tape and then have been analyzed by the digital computer. Parameters of the integrated error value, the auto-correlation function, and the power spectrum of these error values were calculated. Changes between the motor control before and after BFT have been examined in the auto-correlation function, and performance in BFT have been estimated with the gain (amplitude) and the frequency (phase) of the power spectrum. This motor control is simulated by a model of the motor sensory system in Figure 1.

In Figure 3, performance curves of the motor control in Exp. 2 are shown for one subject of EG.

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Experimental proposals about the pursuit tracking with rectified EMG(Exp. 1) and the compensatory tracking with muscular tension(Exp. 2)</th>
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<tbody>
<tr>
<td>Exp. 1</td>
<td>visual &amp; auditory pursuit tracking constant (static) value of rectified EMG M. Biceps Brachii 3days healthy adults 6men (1) integrated error value (2) EMG Power Spectrum (3) flexion tension</td>
</tr>
<tr>
<td>Exp. 2</td>
<td>visual compensatory tracking constant value of muscular tension M. Biceps Brachii 31 trial (1.5hrs) 6men (visual) 5men (blind) (1) integrated error value (2) EMG Power Spectrum</td>
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Integrated error values of the parameter are sampled for 20 seconds in each trial. Before BFT, this average value of EG is 110 (arbitrary unit) and that of CG is 82. After BFT, these values are lower level than that before BFT, that is 78 in EG and 91 in CG. Performance of EG has been remarkably improved in the better motor control after BFT while performance of CG has shown little changes on the ratio of about 10%.

A comparative study on the motor control (performance) before and after BFT shows that t value is calculated as 0.834 (p < 0.05).

Figure 4 shows the difference of the motor control in the integrated error value before and after BFT. These changes of the error value in the time course of BFT have been analyzed by the power spectrum.

**Figure 3** Comparative records with the experiment 2 signals of Biofeedback training each trial
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Figure 4 Performance (integrated error value) changes in two trials of the pursuit and the compensatory recordings

The example of the spectrum in Exp. 1 is shown in Figure 5.

The power spectrum shows that the gain and the frequency in the motor control are estimated in the open loop model of the sensory motor behavior. This chart has shown the power density (gain) in the longitudinal axis according to the motor control rhythm (frequency) in the transversal axis. Figure 5 shows the example of the standard power spectrum among subjects in the present experiment. The remarkable power appears in two frequency bands of 0.4—0.8 Hz and 1.15—1.25 Hz below 40 db after BFT, but in spectra before BFT, flat power is gotten in the whole frequency bands (0.2—2.0 Hz).

Changes of the average value of the muscle strength are shown in Figure 6 at the time course before and after BFT of Exp. 1. In comparison between the muscle strength before and after BFT, the upper arm strength of EG have decreased to the lower value after BFT, while those of CG have shown no changes.

Average values of the strength are shown 5.8, 3.5 and 2.1 kg in high, middle and low levels respectively before BFT of EG, and after BFT these values are changed to 4.1 (high), 2.8 (middle) and 1.7 (low) kg.

Figure 5 Comparative power spectra of error values before and after the biofeedback training in the case of Exp. 1.

Figure 6 Muscle strength changes at the trial course before and after BFT according to middle level

The difference shows the statistical significance (p<0.01) while three average values of CG are 6.9, 5.2, and 1.9 kg at each respective value before BFT, and after BFT, these values are no changeable at 7.2 5.1 and 2.6 kg. Decreasing ratios are about 30.5% and 5.0% in each EG and CG, respectively.
DISCUSSION

In the biofeedback research for the motor control, the most important things that the good system of the biofeedback method has been manufactured in order to be able to practice the motor control. In the present study, this system should have been completed with the special system of the sensory motor control, and this system was applied for BFT to keep the constant value of EMG's signals in healthy subjects. Surface EMG's signals are controlled to keep the constant value and these experimental subjects are trained to increase the motor performance by BFT with the visual and auditory informations.

Other usages of EMG's signals have been reported in the applicative fields of the plastic surgery about the muscle rigidity or spasm (Jacobs & Felton, 1969). Also, for the application and the detection of many muscular contractions, EMG's signals have been used to the prescription for patients. On these backgrounds, BFT has been considered to be a kind of motor control training.

By the measure of the present BFT, covert signals in the peripheral motor sensory system should have been changed for subjects to acknowledge as the overt information in the central nervous system. Covert EMG's signals have been transfered to overt visual and auditory sensations, and then these signals have been controlled to be kept in the condition of the motor tracking.

After BFT in Exp.1 and Exp.2, in spite of the blocking to feedback information, effects of performance and retention on the motor control have appeared with skillful behavior significantly while effects on the sensory mechanism have much difficulty to explain by present data of physiological and psychological demonstrations. But, by the method of the analysis of variance, the difference between data before and after BFT has been demonstrated to be significant.

A model of the motor control is shown in the block diagram of Figure 1, which should be co-activated between two factors of the feedback and the feedfoward functions. The feedfoward control is assumed to correspond to the predictive function or the anticipative movement. Then, this function might have been activated more effectively than the other feedback function in BFT. The central nervous system would be conformed to the feedfoward function, while the peripheral nervous system would be corresponded to the feedback one. The more skillful the motor control should be practiced in the tracking, the more effectively predictive function should be constructed in the central nervous system.

By the repetitive BFT, the motor control performance should have enhanced with appearance of a little integrated error values between the command and EMG's signals. The control performance should have been improved after BFT significantly. The analysis of variance has shown the performance increase after BFT. The initial performance in EG of two experiments had been inferior to that in CG, and EG would be expected to enhance to higher level in the motor performance than that of CG. As the result, EG have had the better performance in two experiments. Data of proving the reinforcement had not collected in the present study, because the performance difference between EG and CG had been too larger variance to compare the performance change before and after BFT.

The judgment of BFT effects is thought to be difficult especially in the case of healthy subjects of this experiment, who have much more different performance and characters at the beginning period of the experiment than that of patients. If patients with poor muscle contractions would be applied to this BFT, they would show more remarkable effects on the motor control. BFT system have been manufactured to be convenient for many kinds of subjects to control muscle contractions, and then any person could transfer the motor control function from the feedback control to feedfoward one. Patients would use this feedfoward function more
effectively than healthy persons of the present study.

In consideration with respect to the power spectrum of error values (Figure 5), the most optimal frequency in the motor control is appeared in the frequency band between 0.2 Hz and 2.0 Hz. This frequency band should indicate that the transfer function of the motor control might be calculated in the condition of the low-pass filter function, and its equation should be estimated with the lag time and the gain (amplitude) in the open loop model (Gottlieb, Agaswal & Stark, 1969). The circuit gain is calculated as 1/1+G(refer to G; the circuit gain) from the motor control model(Figure 1). The gain (G) corresponded to the circuit total amplitude or power.

Two frequency bands in the power spectrum should show the motor control rhythm of the good performance. Frequency changes before and after BFT might suggest for the remarkable effects on the low-pass filter function. After BFT, EG of Exp.1 have changed their transfer function with the optimal frequency and the gain. Such many parameters as the amplitude, the phase, the rhythm, and the time-delay should be considered on denoting BFT effects on the motor control.

The power spectrum before BFT have not shown any oscillation curves or any frequency changes. The constant spectrum might show no frequency margin in the motor control and be possible to have much effects on the performance by BFT. In the comparision of spectra before and after BFT, the control rhythm should be characterized in the low frequency. After BFT, the more narrow frequency band has appeared remarkably and the control delay has not appeared silently. Phenomena obtained in the experiment would show that the motor control function has been altered to be activated on the optimal frequency band. Surely, the gain(G) has also changed to the higher level in the control function.

The muscle strength of the upper arm, after BFT in Exp. 1, was at lower level than that before BFT. The decreasing change in EG should enhance the efficiency of muscle contractions about 40% in the result of BFT effects at both experiments. Higher efficiency mechanics in the motor control should appear at the decreasing ratio of muscle strength and EMG's signals before BFT to that after BFT. The mechanics might be assumed to be one control factor dependent upon the optimal motor behavior. A little energy consumption should be supplied for the constant performance and should indicate the alteration of the transfer function for the better control movement.

In other words, the ratio of the motor efficiency before BFT to that after BFT is calculated using the function of P/M, in which P is the performance from the integrated error value and M is the energy from the muscle strength. P/M ratio has appeared at the lower value efficiently after BFT. The decreasing ratio showed the statistical significance for calculation of t value (p<0.01).

BFT should have had much effect on the motor control with EMG's signals remarkably, and then this present method of BFT might be applied to the development of the muscle contraction in the future. Some comparative studies with Exp. 1 and Exp. 2 should be necessary to be practiced in both fields of the physiological and psychological applications to healthy and patient subjects. Then, the design and the system of the biofeedback training would be expected to be established for much effects on the motor control. In the future, the best BFT system should be applied to the coaching of sport and the diagnosis of disease.

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