On facilitating method for skill acquisition of robot arm manipulation using surface myoelectric signals

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Abstract. In these days, various control systems for robot arms using surface myoelectric signals have been developed. Abundant pattern recognition techniques have been proposed to predict human motion intent based on these signals. However, it may become burdensome for users to train voluntary control of myoelectric signals with these systems. In this study, we are seeking to develop schemes to evoke surface myoelectric signals and facilitate skill acquisition of robot arm manipulation. In this paper, we construct a simple 1-link robot arm which is controlled by estimating the wrist motion from the surface myoelectric signals on the forearm. We make several training experiments for skill acquisition of robot arm manipulation with and without physical constraints of the wrist, or with and without mechanical vibration stimulation. Then, we investigate the differences in facilitation effects of skill acquisition comparing with the results from these training experiments.

1. Introduction
In these days, various control systems for robots using surface myoelectric signals such as myoelectric prosthetic hands and robotic rehabilitation support systems have been developed[1][2]. To make higher usability of these systems, abundant myoelectric pattern recognition techniques have been studied to predict human motion intents based on these signals. However, control schemes incorporating pattern recognition techniques struggle with usability due to signal stochasticity and transient changes[3].

In this study, we do not seek to develop novel myoelectric pattern recognition techniques, but develop schemes to evoke and facilitate voluntary surface myoelectric signals. In fact, humans have abilities to acquire physical motor skills inherently. Therefore, an appropriate training method for voluntary control of myoelectric signals may provide higher usability of control systems of robots using surface myoelectric signals. In this paper, we construct a simple 1-link robot arm which is controlled by estimating the wrist motion from the surface myoelectric signals on the forearm. We make several training experiments for skill acquisition of robot arm manipulation with and without physical constraint of the wrist, or with and without mechanical vibration stimulation. Then, we investigate the differences in facilitation effects of skill acquisition comparing with the results from these training experiments.

2. Facilitation of surface myoelectric signals
Movements of body parts are controlled by impulses (messages) from brain through nerve pathways to muscles as shown in Fig.1. It is revealed that nerve pathways can be built up
by making trainings with facilitating stimulations. Thereby, we consider that voluntary control of surface myoelectric signals can also be intensified by training with facilitating stimulations. In this paper, we make several training experiments with physical constraint of a body part, or with mechanical vibration stimulation to facilitate voluntary control of surface myoelectric signals.

3. Robot arm controlled by surface myoelectric signals

3.1. Experimental system
We constructed a simple 1-link robot arm (1-DOF planar link) with a servo motor which is controlled by estimating the subject’s (user’s) wrist motion from the surface myoelectric signals on the forearm as shown in Fig.2. Two electrodes are attached to the skin on the subject’s forearm. One detects the surface myoelectric signals of wrist extensor muscles and the other detects those of wrist flexor muscles.

When the subject extends own right wrist (dorsiflexion) and the intensity of myoelectric signals of the extensor muscles exceeds a certain threshold level, this robot arm rotates clockwise. On the contrary, when the subject flex own right wrist (palmar flexion) and the intensity of myoelectric signals of the flexor muscles exceeds a certain threshold level, this robot arm rotates counterclockwise. However, when intensities of myoelectric signals of both extensor and flexor muscles exceed or do not exceed the threshold simultaneously, this robot arm does not rotate. In order to keep the experimental conditions uniformly, the forearm of the subject is constrained to lie in a pedestal with hook and loop fastener bands, where the wrist can move freely.

3.2. Manipulation task
We set up the task for the robot arm manipulation as follows. The subject has to manipulate the robot arm to perform reciprocating rotary motion quickly at angle 90 degrees in limited
time of 40 seconds. We can evaluate the skill of the subject by investigating the number of reciprocating rotary motions and the accuracy of the rotary angles.

In a pilot study, a first-time beginner could not manipulate the robot arm at all. Then, after making several trials the beginner became able to manipulate the robot arm with performing a few reciprocating rotations. Therefore, it is expected that any subject can acquire the skill of manipulating the robot arm using surface myoelectric signals after some training.

4. Conditions of training for facilitating skill acquisition

4.1. Resistance force against motion of the wrist
In order to stimulate extensor muscles and flexor muscles of the wrist in training, the wrist is constrained not to move on the pedestal. We consider that the resistance force against motion of the wrist evokes the muscle activities. After some training with this condition, we expect that the intensity of myoelectric signal can exceed the threshold easily without wrist constraint.

4.2. Vibration stimulation
We consider an application of vibration stimulation (Fig.3). Two vibrators are attached to the skin on the subject’s forearm. One stimulates the surface of wrist extensor muscles when the subject should extend the wrist, and the other stimulates the surface of wrist flexor muscles when the subject should flex the wrist. After some training with this condition, we expect that the surface myoelectric signals can be evoked on the skin from the appropriate muscles.

5. Training with three conditions and evaluations
We consider three kinds of training experiments to compare the differences in facilitation effects of skill acquisition. One is the training with the condition (Condition-I) in which the subject can move wrist freely. Another is the training with the condition (Condition-II) in which the subject’s wrist is constrained not to move on the pedestal. The other is the training with the condition (Condition-III) in which two vibrators are attached to the skin on the subject’s forearm, and the subject can move wrist freely.

The subject has to perform thirty trials of the task (40 seconds) as training with one of three conditions. In addition, the subject has to perform the initial trial with Condition-I before the training and the last trial with Condition-I after the training. Then we investigate the skill acquisition of the subject by comparing with the numbers of reciprocating rotary motions of the robot arm at the initial and last trials.

6. Training experiments
With cooperation of four subjects (A, B, C, and D: normal subjects in their 20s), the training experiments were conducted. For each subject, the training experiments were conducted twice.

Figure 3. Vibration stimulator composed with two eccentric motors
Table 1. Protocols of the training experiments for four subjects.

| Subject (Right wrist) | Training conditions of the twice experiments |
|-----------------------|---------------------------------------------|
| A                     | Condition-I ⇒ Condition-II                 |
| B                     | Condition-II ⇒ Condition-I                 |
| C                     | Condition-I ⇒ Condition-III                |
| D                     | Condition-III ⇒ Condition-I                |

Table 2. Increased numbers of reciprocating rotary motions of the robot arm

| Subject (Right wrist) | Training | Initial | Last | Increment |
|-----------------------|----------|---------|------|-----------|
| A                     | Condition-I | 2  | 1    | -1        |
|                       | Condition-II | 8  | 16   | +8        |
| B                     | Condition-II | 5  | 15   | +10       |
|                       | Condition-I  | 0  | 5    | +5        |
| C                     | Condition-I  | 0  | 6    | +6        |
|                       | Condition-III | 3  | 10   | +7        |
| D                     | Condition-III | 1  | 2    | +1        |
|                       | Condition-I  | 2  | 0    | -2        |

with different conditions leaving at least one day between them. The protocols of the training experiments for four subjects are shown in Table 1.

For each training experiments, the numbers of reciprocating rotary motions of the robot arm at the initial and last trials are shown in Table 2. Comparing with these results, we can find that the increased numbers of reciprocating rotary motions after training of Condition-II were more than those of Condition-I, and the increased numbers of reciprocation rotary motions after training of Condition-III were rather than those of Condition-I.

7. Conclusions
We have made several training experiments for skill acquisition of a simple 1-link robot arm manipulation with and without physical constraint of the wrist, or with and without mechanical vibration stimulation, where the robot arm is controlled by estimating the wrist motion from the surface myoelectric signals on a forearm. From the results of these training experiments, it can be expected that the training with physical constraint of the wrist or with mechanical vibration stimulation can facilitate the skill acquisition of the robot manipulations using surface myoelectric signals.

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