Wired Muscle: Generating Faster Kinesthetic Reaction by Inter-personally Connecting Muscles

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ABSTRACT

Instantaneously generating own body movements in response to the movement of others, such as establishing defensive posture in sports and learning kick-out timing from therapists in gait rehabilitation, is an essential aspect of interpersonal exercises and contact sports. However, ignition of movement based on a visual stimulus requires approximately 250 milliseconds (ms), which is too late for certain interpersonal physical interactions that require immediate reaction. Thus, we introduce "Wired Muscle," a system that connects muscle activities between two persons using electromyogram (EMG) measurement and electrical muscle stimulation (EMS) to generate responsive movement that are faster than those generated by the visual information-based process. Our system detects the muscle activity of a person by the EMG and triggers the EMS to drive the muscle of the other person to induce corresponding counter movements. In a pilot study using our system, the reaction time to the motion of another person could be shortened to approximately 60 ms. In addition, some participants perceive that the kinesthetic reaction was performed by their own will even though the muscle movement was electrically driven by prior stimuli. We envision that our system will enable direct connection of kinesthetic experiences among multiple persons and will form the basis for a novel paradigm of motor learning.

CCS CONCEPTS

• **Human-centered computing** → **Haptic devices**;

KEYWORDS

kinesthetic experience, electrical muscle stimulation, electromyogram, interpersonal connection

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Figure 1: Wired Muscle: a system for directly connecting muscles of two persons. The EMG detects the muscle activity of a person A, which triggers the EMS to drive the muscle of person B to produce rapid corresponding movements.

1 INTRODUCTION

In physical interaction between humans, such as contact sports and rehabilitation, we are required to generate our own physical responses to the opponent's physical movements. The reaction based on a visual stimulus takes about 250 ms (milliseconds), which includes the time taken to visually register the movement of the opponent, recognize the state, and issue a command to the muscles to execute the response. However, in physical interactions requiring faster reactions, the vision-based reaction is too slow for executing an appropriate response.

Hence, we then introduce a "Wired Muscle" system that directly connects the muscles of two persons (Fig. 1). The system includes the electromyogram (EMG) that measures muscle contractions. In this process, an electrical muscle stimulation (EMS) in one person induces a muscle contraction in another person to execute a corresponding physical action. The EMG is able to detect bio-signals generated by the muscular activity, even if it is difficult to observe visually. Therefore, it is possible to issue the trigger much faster than the visual based process. In addition, as the trigger is captured by the EMG, the EMS generates a kinesthetic movement with somatosensory feedback.

2 WIRED MUSCLE SYSTEM

Figure 2 shows the system architecture for the proposed system. We used a device called **bioSync** comprising a pair of wearable kinesthetic I/O devices [Nishida and Suzuki 2017]. Each bioSync device is equipped with a customized electrode system that performs EMG measurement and EMS simultaneously. In our system, the bioSync

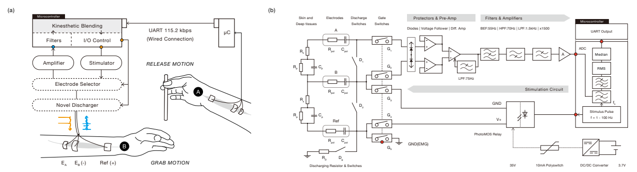

Figure 2: System diagram of Wired Muscle. The system consists of a pair of wearable kinesthetic I/O devices, called bioSync, which performs EMG measurement and EMS simultaneously.

on the person A works as an EMG measurement device to detect the bio-signals related to muscle activity. On person B, the bioSync performs EMS as well as EMG measurement. Each bioSync device is attached to a different body part on each person to generate a corresponding muscle reaction. For instance, in the bar drop test shown in Fig. 1, the bioSync A is attached to the extensor digitorum muscle of the left hand of A to detect an opening motion, and the bioSync B to the flexor digitorum muscle of the right hand of B to induce closing motion. When the bio-signal generated by person A reaches a value higher than a threshold, the bioSync B immediately performs EMS to induce muscle motion in the person B.

3 KINESTHETIC REACTION

In this paper, we demonstrate sequential events using a bar drop test between two persons, a method commonly used to measure the reaction times to a visual stimulus. In this test, person A opens his/her hand to release the bar, and person B tries to grab the falling bar without looking their hands (Fig. 1). Figure 3 shows how the rapid corresponding muscle activity is generated by Wired Muscle and how the self-intended (voluntary) muscle activity is generated through kinesthetic and tactile sensation by EMS. Figure 3 also shows the comparative reaction time (approx. 250 ms) when only a visual stimulus is used. When the person A opens his/her hand to release the bar (Fig.3 -1), the bioSync A detects the bio-signal of the muscle activity and sends the trigger to the bioSync B. The bioSync B then performs EMS (Fig.3 -2) to induce the involuntary muscle contraction to close the hand. With this intervention, the person B is able to grab the dropping bar within a reaction time of 60 ms from the moment the bar is released by person A (Fig.3 -3). Here, the system delay from the detection of the release action by the person A to the EMS drive is approximately 10 ms and the time taken to fire the motor unit to execute the muscle activity by the EMS is approximately 50 ms. The reaction time required for voluntary motion is observed to be approximately 250 ms with visual stimulus and approximately 170 ms with kinesthetic stimulus, depending on the degree of expertise in the exercise. The EMG signal of person B in Fig. 3-4 shows that the voluntary muscle activity came late (approximately 110 ms) after the involuntary motion by the EMS.

4 APPLICATION SCENARIOS

In prior studies, it has been established that since EMS can induce the muscle movement with a voluntary sense of motion, it is possible to generate a haptic feeling of passive force in virtual reality applications [Lopes et al. 2015]. An example of such an approach

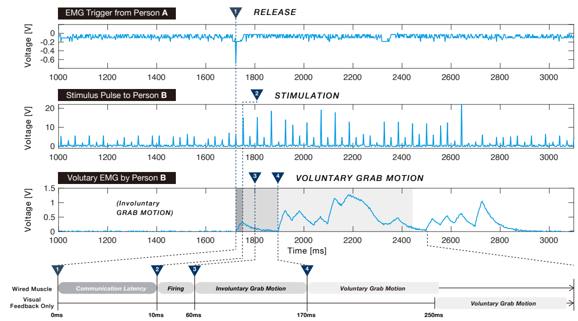

Figure 3: A detailed sequence of the kinesthetic reaction by Wired Muscle.

was used to develop PossessedHand [Tamaki et al. 2011], a device aimed at learning musical instruments by using EMS to drive the user's own muscles to reproduce the recorded body motions. However, contact sports require an immediate reaction to the opponent as well as multiple and unexpected movements. With our system, if the correspondence of appropriate muscle activity is computationally recorded beforehand, kinesthetic reactive motions in various contact sports can be possible. For example, in martial arts, we would be able to learn by experiencing own successful motions responding in time through own kinesthetic sense.

5 FUTURE WORK

Our empirical studies indicate that due to the spatial and temporal consistency between the voluntary movement based on visual stimulus and the involuntary movement through EMS, the two movements could be interpreted as one single faster voluntary movement. In other words, the rapid reaction to others' movement, produced by Wired Muscle, could be perceived as a "virtual" voluntary action, even though it was actually driven computationally. Although the current implementation only drives a single application, we expect that it is possible to extend reaction movements involving complicated muscular activity by using multi-channel functionality. In addition to kinesthetic connection, we also expect that exchanging and sharing visual stimuli [Kasahara et al. 2016] would enhance the spatial consistency of the connected experience and lead to effective motion learning with lower cognitive load.

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