EFFECT OF INTERFERENTIAL CURRENT ON ELECTROMYOGRAM SIGNALS FOR MYOELECTRIC PROSTHETIC HAND

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Abstract: Electrocutaneous stimulation to convey sensory feedback from myoelectric hand prosthesis interferes with the prosthesis control system inevitably. Our purpose is to examine whether the interferential current (IFC) stimulation is useful for transmitting information of myoelectric hand prosthesis to the user. IFC stimulation is composed of two alternating current waves with medium frequency (4000Hz). We evaluated influence of a change in the phase difference of two waves to a position of perceived stimulus. Moreover, we investigated the effects of a distance of electromyogram (EMG) electrodes from stimulating electrodes on the extent of IFC interference with myoelectric signals. As a result, the movement of position of perceived stimulus was caused by the phase difference changing. The interference of IFC with myoelectric signals close to stimulating electrodes was large. In contrast, when pick-up electrodes were distant from the stimulating electrodes, the interference of IFC was small. Moreover, the interference was eliminated by the low-pass filter (< 500Hz). These results suggest the usefulness of IFC stimulation method for sensory feedback and the necessity of the low-pass filter for EMG pick-up system of myoelectric prosthetic hand.

Introduction

In rehabilitation engineering, electrocutaneous stimulation is used for a transmission of device information to the user [1, 2, 3]. This information represents the primary function of the device, such as visual or auditory prostheses, or it does the feedback function which improves the usefulness of the device, as in sensory feedback from a prosthetic hand.

A powered prosthetic hand is used to replace the functions of a natural hand. Many kinds of powered prosthetic hands, including a system equipped with an electromyogram (EMG) signal controller, have been developed. For example, Okuno et al. [4, 5] developed a prosthetic hand which mimicked the fundamental dynamic properties of the neuromuscular control system of the natural human hand (see Fig. 1, solid line). In their experiment, a user of a conventional prosthesis could grasp a soft object (a cream puff) easily and smoothly with this prosthetic hand. However, such myoelectric prosthetic hand is not equipped with a sensory feedback system which returns information of the device to the operator (see Fig. 1, dotted line). Therefore, to get the state of prosthetic hand, such as finger angle, the operator can do nothing but rely on visual information.

Many researchers [6, 7, 8, 9] have studied on a sensory feedback system for sensory communication between prosthetic hand and man in various methods. Tactile displays for sensory substitution system includes mechanical vibration and electrocutaneous stimulations. Electrocutaneous stimulation is useful for sensory feedback. Electrocutaneous stimulators have no moving parts and maintain a constant contact with the skin. In addition, they are efficient in terms of power consumption.

Typically, the electrocutaneous stimulation with monophasic or biphasic current pulse is applied. In this case, frequency of pulse train is low in less than 200Hz [2, 7]. This method has defects (e.g., high impedance of skin, development of pain, and so on). In addition, signals of electrical stimulation interfere with myoelectric signals. There are most of frequency components of myoelectric signals in less than 500Hz. Therefore, it is difficult to distinguish original myoelectric signals and interferential signals of electrical stimulation during transmitting information of prosthetic hand to the operator. Hence, during transmitting the information of the prosthesis to the manipulator using this electrical stimulation, the control system of myoelectric hand prosthesis must interrupt control of opening and shutting prosthetic hand.

An interferential current (IFC) method settles the problems above-mentioned, because IFC stimulates internal organization through a skin. Normally, IFC makes two alternating current (AC) waves with medium frequency interfere to synthesize in the body. We previously confirmed that IFC method could change the intensity of perceived stimulation with no pain [10]. However, there were some interference of IFC with myoelectric signals. We thought that it is easy to discriminate between original myoelectric signals and IFC interference signals, because the frequency of AC output for IFC stimulation is far higher than frequency components of myoelectric signals. For myoelectric prosthetic hands, it is desirable to detect accuracy myoelectric signals. In the present study, we 1) confirm whether IFC method can move the position of perceived stimulus without moving stimulating electrodes, and 2) investigate the effect of a distance of recording electrodes from stimulating electrodes and the necessity of low-pass filter for elimination of interference

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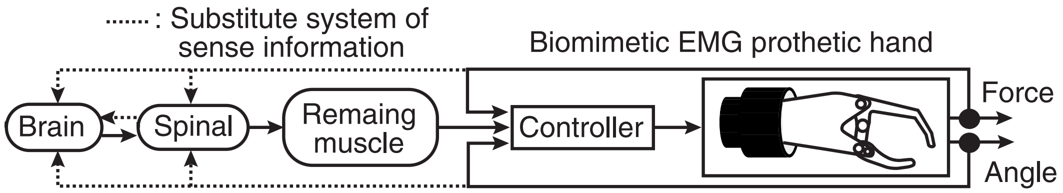

Figure 1: A simple diagram of the biomimetic hand. Dotted lines indicate potential routes of sensory feedback. These sensory feedback systems include the sensory substitution system with electrocutaneous stimulation or mechanical vibration stimulation on the skin surface and the electrical stimulation of afferent nerve. The present powered hand prostheses has no sensory feedback system.

of IFC stimulation with EMG.

Materials and Methods

Stimulating method

To get information of the prosthetic hand, it is very important that a control system of the prosthetic hand has its own support type and its own built-in type. In this view point, the sensory feedback system using an electric stimulation has more beneficial effect than mechanical vibration stimulation, because it is possible to make the system small and its energy consumption low. However, when the electric stimulation is applied near recording electrodes for EMG, we must consider the problems, such as skin impedance, pain and interference with myoelectric signals for the control system.

IFC method settles problems of skin impedance and pain, because an electric power of IFC stimulates internal organization through a skin. Normally, an electric stimulation has the frequency within a few hertz up to about 200Hz. In this case, the skin impedance is high. On the other hand, the typical IFC stimulator utilizes two sinusoidal AC output circuits that is approximate 4000 to 5000Hz. In this frequency range, the skin impedance is low.

Merits of IFC are the followings.

1) Electric current occurs in the body and is safe.
2) We can choose a stimulating region by arranging position of electrodes and changing size.
3) Skin impedance is low, because the frequency of the current going through the skin is high.

In our previous studies, we confirmed that IFC stimulation, using two sinusoidal AC output circuits that differ somewhat in frequency, is useful method for sensory feedback device of a prosthetic hand. However, there is still open to discussion about interference of IFC stimulation with myoelectric signals.

Movement of the perceived region (Study 1)

In our previous study [10], we confirmed the usefulness of IFC method for a painless stimulation. IFC stimulator utilizes two sinusoidal AC output circuits.

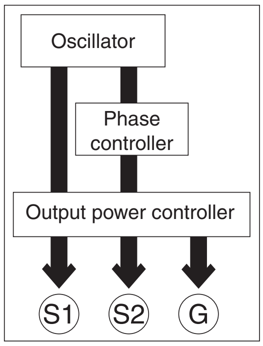

Figure 2: Hardware of interferential current stimulator

When these two outputs intersect, the frequency difference causes the sine waves' amplitudes to summate, resulting in the so-called "beat". In the previous study, we fixed four electrodes so that two channels crossed in a cross section of an upper arm. We succeeded in changing strength of perceived stimulation by changing a "beat" frequency. Then, in the present study, we confirmed whether controlling of phase difference between two AC outputs with the same frequency moves position of perceived IFC stimulation.

We made the IFC stimulator which generates two sinusoidal AC outputs. This device can change the output voltage and output phase as the figure 2. Frequencies of S_1 and S_2 are the same (5000Hz). S_1 output is not operated by the phase controller. S_2 output is operated by the phase controller. G is the ground. The range of output voltage is 0 to 8V and the range of phase difference between two waves is 0 to 180 degree.

Four young healthy subjects participated in study 1 of the present study. We used a stainless steel electrode (ϕ : 10mm) for IFC stimulation. The electrically conductive paste was put there, and fixed on biceps brachii wiped with alcohol. The configuration of stainless steel electrodes was as the figure 3. We drew this scale on subject's arm with the marker. The subjects were made to represent a region of perceived stimulus as the numerical value. The subjects sit on a chair and relax their arm.

We made a phase change of S_2 in the following four patterns (A), (B), (C) and (D). And we went in the order of the table 1. The subjects represented the position

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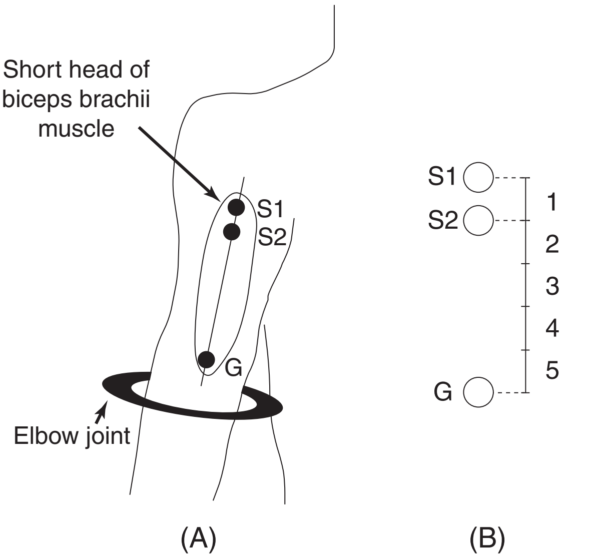

Figure 3: Electrodes configuration (A) and the region of perceived electrical stimulation divided into five equally space(B).

Table 1: The turn of the experiment

First day	Second day	Third day
(A)	(D)	(A)
(B)	(C)	(B)
Repose*	Repose	Repose
(C)	(B)	(C)
(D)	(A)	(D)

*Repose is 10 minutes.

which they perceived a stimulus with on the scale. This scale divided into 5 equally space was used as figure 3(B).

(A) The phase difference between S_1 and S_2 is changed every 10 degree from 0 to 180 degree.

(B) The phase difference is every 10 degree from 180 to 0 degree.

In condition (A) and (B), the subjects were made to express a region which is perceived the stimulus on the scale.

(C) The phase difference is changed continuously from 0 to 180 degree.

(D) The phase difference is changed continuously from 180 to 0 degree.

In condition (C) and (D), the subjects were made to express in which direction on the scale the position of perceived stimulus moved.

Interference of IFC with myoelectric signals (Study 2)

In a myoelectric hand prosthesis, there is the problem of interference of electrical stimulation with myoelectric

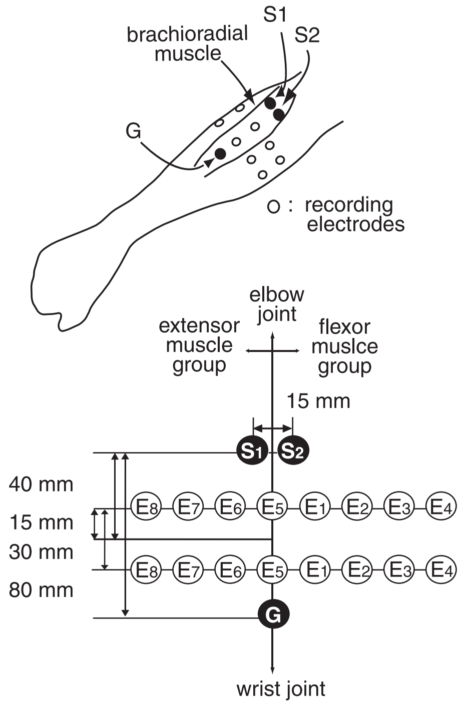

Figure 4: Stimulating and recording electrodes configuration. S_1, S_2 and G were stimulating electrodes. $E_1 \sim E_8$ were recording electrodes. Distance between each channels is 20 mm.

signals when electric stimulation is used for transmitting information of the prosthetic hand to the manipulator. We previously confirmed that the low-pass filter (LPF) eliminated the interference of IFC stimulation [10]. In the previous study, the regions of EMG recording and electrical stimulation were different. EMG of wrist flexor muscles were measured and IFC stimulations were applied to the upper arm. When we develop the compact device equipped with myoelectric controller system and sensory feedback system, it is desirable that both systems centralize on one region, such as a forearm.

Then, to evaluate the influence of IFC stimulation to the forearm on EMG of the wrist flexor and extensor muscles, we arranged the configuration of the stimulating and recording electrodes as the figure 4. The stimulating electrodes were stainless steel electrodes (ϕ : 10mm). The recording electrodes were Ag-AgCl electrodes (ϕ : 5mm). Before the setting the electrodes, the skin was whipped with alcohol. To clarify how much distance between stimulating and recording electrodes is necessary to remove the interference of IFC stimulation with myoelectric signals by LPF, we measured EMG with some configuration of recording electrodes. The bottom panel of figure 4 shows the configuration of recording electrodes for EMG of wrist flexor and extensor muscles. Simultaneously, we arranged the recording electrodes on the surface of extensor muscle group.

EMG were measured (sampling rate: 10kHz) for a 3 seconds of following conditions.

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- Static contraction of flexor muscles with and without IFC stimulation
- Static contraction of extensor muscles with and without IFC stimulation

IFC stimulation was composed of two sinusoidal AC outputs with 4000Hz of frequency. Phase difference between the two outputs was changed every 10 degree within 0 to 180 degree.

For EMG recording, we used the integrated circuit of EMG amplifier (NB6101HS; NABCO, Japan). We show a frequency characteristic of this integrated circuit in the following: (1) 2.3Hz of low cut-off frequency (1-order high-pass filter), (2) 350Hz of High cut-off frequency (1-order low-pass filter).

Thereafter, to evaluate the usefulness of LPF for elimination of the interference of IFC stimulation with EMG signals, we compared *off-line* the EMG with and without the filter. The cutoff frequency of this filter was 500Hz.

Results and Discussion

Movement of the perceived region (Study 1)

Figure 5 shows the results of the conditions of (A) and (B) in all subjects. Left and right panel of figure 5 indicate results of condition (A) and (B), respectively. Thin, dotted and thick lines show results on first, second and third day, respectively. All except subj. 2 showed that the position of perceived stimulus moved from the distal to the proximal position as the phase difference incenses in condition (A). Conversely, all except subj. 2 showed that its position moved from the proximal to the distal position as the phase difference decreases in condition (B). In addition, figure 5 shows that the result of third day is clearer than that of first day for the relationship between the change in the phase difference and the change in the position of perceived stimulation. The subjects might have been causing the habituation to IFC stimulation by doing the experiment repeatedly.

Figure 6 shows the results of the conditions of (C) and (D) in all subjects. The differences of the line types is the same as those differences in figure 5. The results of all subjects except subj. 2 showed that the position of perceived stimulus moved in the direction from distal to the proximal position as the phase difference increased continually as well as figure 5. Similarly, it was shown to move in the direction from the proximal to the distal position with continual decrease of the phase difference.

These results suggest that the position of perceived IFC stimulus can be moved by controlling the phase difference. For the results of subj.2 of the third day, there might be a problem in the setting of the experiment.

Interference of IFC with myoelectric signals (Study 2)

Figure 7 shows the effects of LPF on the interference of IFC with myoelectric signals. The upper panel

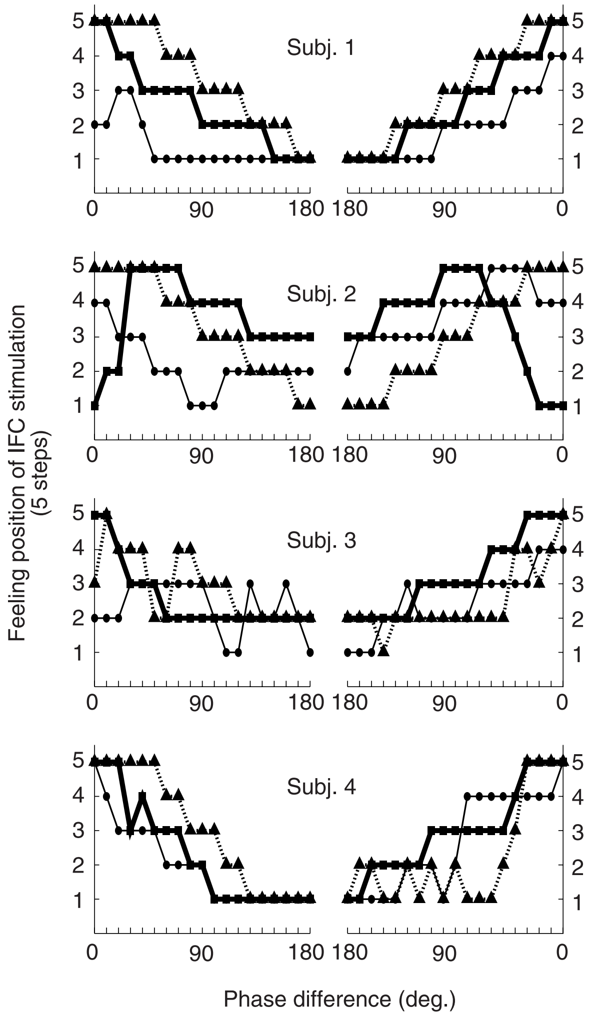

Figure 5: Change in position of perceived stimulus with different degree of phase difference between two AC outputs for four healthy subjects. Left and right columns indicate results of condition “(A)” and “(B)”, respectively. Thin line with circle indicates a results of first day, dotted line with triangle indicates its second day, and thick line with square indicates its third day. indicate

of this figure shows the power spectrum of EMG of extensor muscles at 40mm distance from the S_1S_2–G axis without LPF during contraction of wrist extensor muscles group. In this panel, the peak frequency on right edge corresponded to the frequency of AC outputs (4000Hz). Although our EMG recording system has the LPF characteristic of 350Hz in cutoff frequency, the influence of IFC on EMG was too large, and it was not removed with this first-order LPF of the recording system (see the gray zone of upper panel in Fig. 7). In the case of electrical stimulation of afferent nerve, because an electric current used for electrical stimulation is low, an interference with EMG is low [9]. However, IFC method of electrocutaneous stimulation utilized higher voltage than its electrical nerve stimulation. Therefore, this interference of IFC with myoelectric signals was larger than original myo-

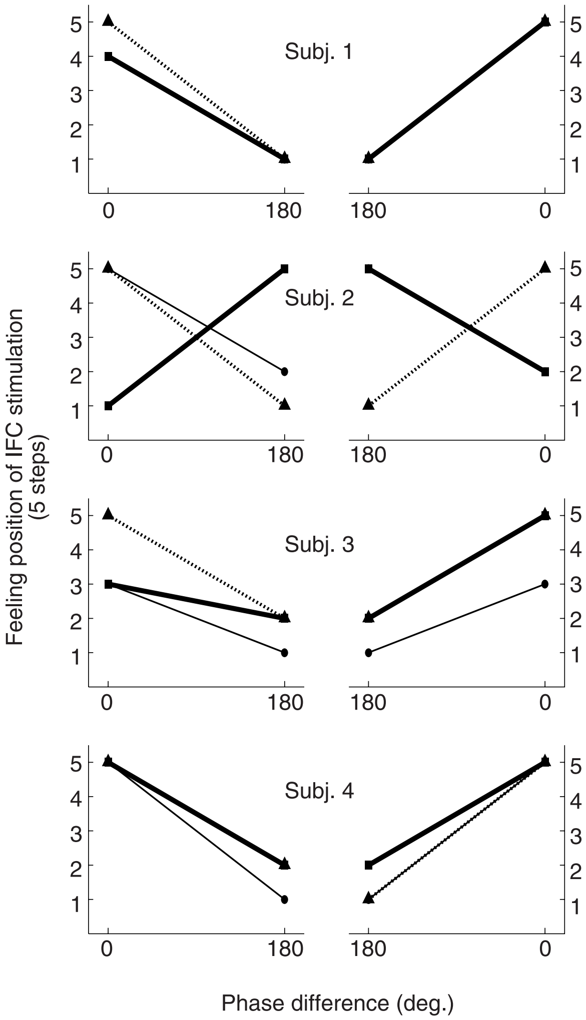

Figure 6: Direction of moving position of perceived stimulus with change from 180 to 0 or from 0 to 180 continously. Left and right columns indicate results in condition "(C)" and "(D)", respectively. Difference of line type is the same as figure 5.

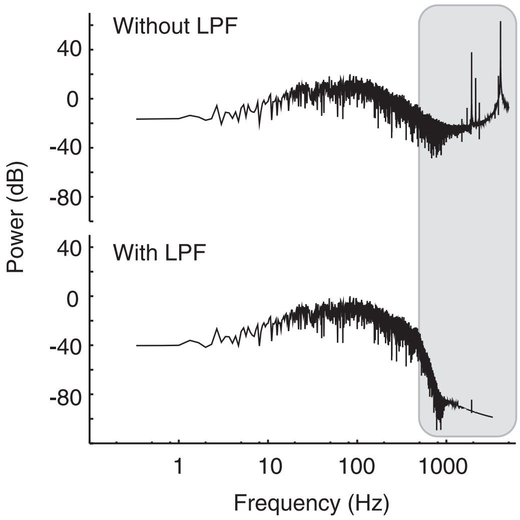

Figure 7: Frequency characteristics of the low-pass filter (LPF). The power spectrum of EMG signals were measured at 40mm distance from the S_1S_2–G axis during contraction of extensor muscles. Note that most of frequency components of EMG signals (< 500Hz) remained almost completely with LPF (the bottom panel).

electric signals within 0 to 500Hz. The bottom panel of figure 7 shows that the interference of IFC with myoelectric signals was removed by the additional LPF (eight-order).

Figure 8 shows the effect of the distance of recording electrodes from the S_1S_2–G axis and the effect of the eight-order LPF on interference of IFC with myoelectric signals. The top lines in figure 8-A and 8-B represent EMG during static contraction of the wrist flexor muscles without IFC stimulation (A, flexor muscles; B, extensor muscles). Simultaneously, the middle (A-(b) and B-(b)) and bottom (A-(c) and B-(c)) lines represent EMG without and with the LPF, respectively, during contraction of flexor muscles and IFC stimulation. In each figure of (A) and (B), the left column shows the results of EMG at a distance of 20mm and 0mm from the S_1S_2–G axis respectively. The second, third and firth columns in figure 8-A and 8-B show the results of recording signals at a distance of 40 and 20, 60 and 40, and 80 and 60mm, respectively. These results indicated that the LPF eliminated the interference of IFC stimulation with myoelectric signals during static contraction of the flexor and extensor muscles. However, EMG of extensor muscles, which was recorded at a distance of 0mm, were out of range.

The phase difference was smaller, the interference of IFC stimulation was larger. And, the closer distance between stimulating and recording electrodes was, the larger interference developed. In the case of the phase difference with 0 degree, EMG of flexor and extensor muscles at a distance of 20mm and 0mm from the S_1S_2–G axis, respectively, were out of range. These results indicated that the eight-order LPF eliminated completely when recording electrodes were arranged at a distance of 40mm from the S_1S_2–G axis at least.

Conclusions

These results indicated that there were large interferences of IFC stimulation with myoelectric signals close to stimulating electrodes. Conversely, when the recording electrodes were distant from the axis of stimulating electrodes, the interferences were small. Moreover, the LPF could eliminate the interferences when the recording electrodes were distant, such as at a distance of 40mm from the axis. Therefore, it is suggested that we can develop the myoelectric controller device equipped with a sensory feedback system using IFC stimulation by using a LPF and avoiding an arrangement of recording electrodes on the muscle close to stimulating electrodes.

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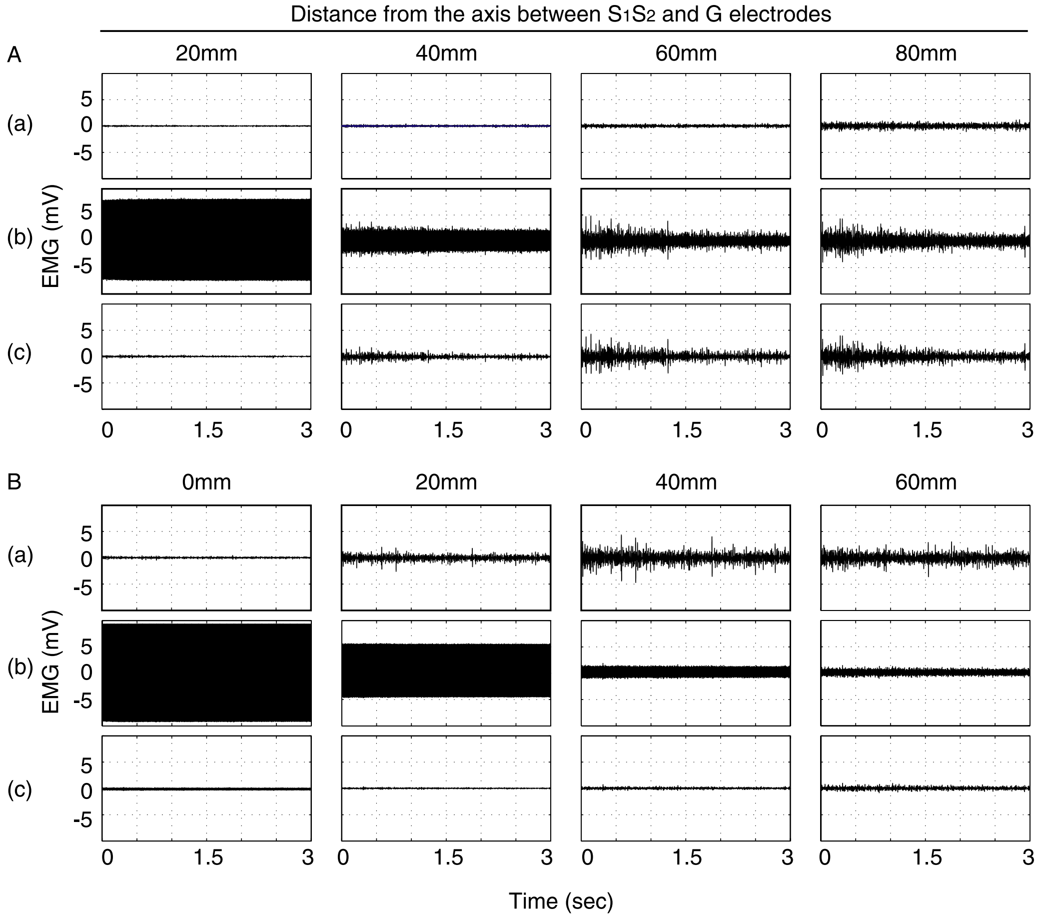

Figure 8: Effects of the low-pass filter and the configuration of recording electrodes on interference of IFC stimulation with EMG signals during static contraction of the wrist flexor muscles. (A)flexor muscles and (B)extensor muscles. A-(a), A-(b), A-(c) and A-(d) indicate results of EMG at 20, 40, 60, and 80mm distance from axis of S_1S_2-G, respectively. B-(a), Similarly, B-(b), B-(c) and B-(d) indicate results of EMG at 0, 20, 40 and 60mm, respectively.

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