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Effects of Electrical Noise to a Knee Joint on Quiet Bipedal Stance and Treadmill Walking*

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Abstract— **The present study assessed whether an unperceivable, noise-like electrical stimulation of a knee joint enhances the stability of quiet bipedal stance and treadmill walking in young subjects. The results showed that the slow postural sway measures in quiet bipedal stance were significantly reduced by the electrical noise (*P*<0.05). In the treadmill walking, low frequency component (below 1 Hz) of mediolateral acceleration, measured at the third lumbar vertebra, significantly decreased with the electrical noise (*P*<0.05), while there were no changes in the anteroposterior and vertical directions. These results indicate that the electrical noise to a knee joint can be applied to enhance postural control in quiet bipedal stance and treadmill walking.**

I. Introduction

Previous studies have suggested that unperceivable mechanical noise to soles of feet [1, 2] and a fingertip in active light touch [3] decreased postural sway during quiet standing, possibly by enhancing somatosensory feedback from the mechanoreceptors. Similarly, a minute, noise-like electrical stimulation of a knee joint [4] and an ankle joint [5] stabilized unstable one-legged standing, while modality of the injected noise was different from that of the mechanoreceptor. In terms of clinical relevance, the electrical noise, instead of the mechanical one, is occasionally preferable because of its portability and stability. That is, the application of the electrical noise to a therapeutic device, which improves the postural equilibrium, is expected. In this study, in order to develop the knowledge about effect of the electrical noise on postural control system, we applied the electrical noise of a knee joint to quiet bipedal stance, much more stable than the one-legged standing and generally employed in daily activities (*experiment 1*). Also, effect of the electrical noise of the knee joint on treadmill walking was investigated (*experiment 2*).

II. Procedure

A. Experiment 1

Twelve subjects (23-39 yrs) maintained quiet bipedal stance on a force platform (EFP-S-1.5kNSA13B, Kyowa) for 30 s. They kept their eyes closed during the measurements. A pair of stimulation electrodes (Ag/AgCl, 14mm diameter, P-00-S, Ambu) was placed on the lateral and medial sides of the knee joint in the right lower limb. A white-noise-like electrical stimulation (frequency range 5–1000 Hz) was applied to the joint. The stimulation intensity was 3 V, well below the sensory threshold of each subject. Trials with noise and without noise were, respectively, repeated eight times, in random order. The anteroposterior sway of the center of pressure (CoP) was measured. Also, to estimate the anteroposterior sway of the center of mass (CoM), we measured the position of the third lumbar vertebra using a high-accuracy laser displacement sensor (LK-500, Keyence) [6]. The CoP and CoM data were sampled at 100 Hz and low-pass filtered at 15 and 4 Hz, respectively, by a finite impulse response digital filter [3, 6]. The mean velocity (total path length/time), the average amplitude, the peak-to-peak amplitude, and the standard deviation (S.D.) of the CoP and CoM fluctuations were evaluated. The frequency power spectrum of CoP sway was assessed by a 2048-point fast Fourier transform with the Hamming window function.

B. Experiment 2

Nine subjects (22-24 yrs) walked on a treadmill for 120 s at their comfortable velocity. The electrical noise was applied to the right knee joint, in the same manner with the *experiment 1*. The intensity of noise was 90% of the individual sensory threshold. The trials repeated four times. The noise stimulation was injected in either the first half (i.e. 0–60 s) or the second half (i.e. 60–120 s) of the each 120-s trial (randomly assigned). A triaxial-accelerometer (Range ±2G, CXL02LF3, Crossbow) was attached on the subject's back. The height of the accelerometer was adjusted to the third lumbar vertebra. Also, a pair of foot switches was attached on the soles of the feet. The data were sampled at 100 Hz (Fig. 1). The output from the accelerometer was low-pass filtered at 1 Hz by a finite impulse response digital filter. This was because, in the *experiment 1*, the electrical noise to the knee joint mainly reduced the slow postural sway measures. The average amplitude, the peak-to-peak amplitude, and the S.D. of the acceleration in each axis during treadmill walking were calculated for each stimulation condition. The average and S.D. of the length of strides were also evaluated.

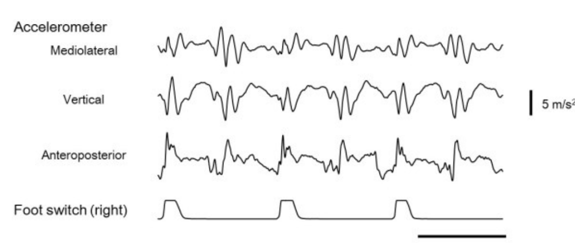

Figure 1. Example of the signals during treadmill walking.

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III. Results

A. Experiment 1

For the CoP sway, the average amplitude, the peak-to-peak amplitude, and the S.D. were significantly decreased by the electrical noise to the knee joint ($P<0.05$, paired-ttest). The mean values were decreased by 7.7%, 8.9%, and 8.4%, respectively. The power spectra of CoP sway, ensemble averaged across subjects for each condition, suggest that the noise effect was mainly accounted for by the reduction of the low frequency component (below 0.5 Hz). For the CoM fluctuation, the peak-to-peak amplitude and the S.D. were significantly attenuated in the noise condition ($P<0.05$, paired-ttest). The mean values were reduced by 10.7% and 8.9%, respectively.

B. Experiment 2

As shown in Table 1, the unperceivable, noise-like electrical stimulation of the knee joint significantly reduced the average amplitude and the S.D. of the acceleration of the third lumbar vertebra in the mediolateral direction ($P<0.05$, paired-ttest). However, the reduction of mean values were relatively small (i.e. 3.6% and 3.5% in average amplitude and S.D., respectively), compared to that of the quiet bipedal stance found in the *experiment 1*. The reduction was shown only in the mediolateral direction and there were no changes in those of the anteroposterior and vertical directions ($P>0.05$). The average and S.D. of the length of strides were not changed by the noise injection ($P>0.05$).

IV. Discussion and Conclusion

The present results showed that the unperceivable, noise-like electrical stimulation of the knee joint enhanced postural stabilization during quiet bipedal stance and reduced the acceleration of the third lumbar vertebra only in the mediolateral direction during treadmill walking. In the quiet bipedal stance, the effect of electrical noise was mainly observed in the slow postural sway measures. In the previous studies [3], we found that the minute mechanical noise stimulation to the fingertip during active light touch reduced a fast postural sway measure (i.e. CoP total path length per unit time) and high frequency sway (1–10 Hz) of CoP. Similarly, Magalhaes and Kohn [7] reported that a larger noise-like vibration on the fingertip during active light touch reduced slow postural sway measures such as area of the stabilogram, RMS of CoP, and low-frequency sway (0.05–0.5 Hz) of CoP. The differences between the two studies [3, 7] are accounted for by the wide range of variation in the activation threshold among mechanoreceptors [8].

TABLE I. Group means of measures of acceleration in mediolateral direction under each conditon

	Stim	Con	P value
Average amplitude (m/s^2)	0.174 ± 0.020	0.180 ± 0.019	0.019 ※
Peak-to-peak amplitude (m/s^2)	0.859 ± 0.072	0.896 ± 0.069	0.051
S.D. (m/s^2)	0.200 ± 0.022	0.207 ± 0.021	0.019 ※

* $P<0.05$ by a paired-ttest. Data are mean ± standard error.

In other words, the optimal intensity of noise injection for a non-linear system (i.e. sensory receptor) is determined by its activation threshold [9]. And a sensory system is composed of a number of sensory receptors, with different activation thresholds. So, the optimal noise intensity must be different among receptors, and it can be assumed that the minute intensity of noise selectively enhances the receptors with low activation thresholds, while larger noise enhances the receptors with high activation thresholds. Thus, even though the noise was injected to the same sensory system, the minute noise reduces the minute, fast postural sway, while the larger noise reduces large, slow postural sway. Therefore, the present result, that the electrical noise reduced slow postural sway measures, suggests that the noise effect was mainly occurred in the sensory receptors with relatively large activation threshold.

In the treadmill walking, the effect of electrical noise on the acceleration was relatively small compared to that for quiet bipedal stance. The possible reason was that, in the present study, the intensity of injected noise was fixed throughout the experiment, in order to avoid the fatigue of the subject by conducting a lot of trials. However, the optimal intensity of noise must be different among receptors, as mentioned above, and may be different from subject to subject. While the present study experimentally indicated that the electrical noise to the knee joint significantly reduces the mediolateral acceleration of the third lumbar vertebra during treadmill walking, further studies are required to systematically investigate the effect of amplitude of noise on the postural control system.

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