Noise-enhanced balance control in older adults

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Somatosensory information is critical to balance control and fall prevention in older adults. Recently, it has been shown that low-level input noise (electrical or mechanical) can enhance the sensitivity of the human somatosensory system. In this study, we tested the effect of low-level electrical noise, applied at the knee, on balance control in 13 healthy elderly volunteers. Subjects performed multiple single-legged stance trials with imperceptible electrical noise applied at the knee during half of the trials. Balance performance was characterized using a force platform to measure the displacement of the center of pressure (COP) under the subject's stance foot. Seven sway parameters were extracted from the COP time series. Improved balance was defined as a reduction in postural sway as indicated by decreases in the COP measures. Six of the seven sway parameters decreased with electrical noise. Three of these parameters decreased significantly ($p < 0.05$), and a fourth parameter was borderline significant. Averaged across subjects, the application of electrical noise resulted in a 3.8% reduction in mediolateral COP standard deviation ($p = 0.04$), a 5.4% decrease in the maximum anteroposterior COP excursion ($p = 0.03$), a 3.1% reduction in the COP path length ($p = 0.04$), and a 7.8% decrease in swept area ($p = 0.05$). The results suggest that imperceptible electrical noise, when applied to the knee, can enhance the balance performance of healthy older adults. These findings suggest that electrical noise-based devices may be effective in improving balance control in elderly people. *NeuroReport* 13:1853–1856 © 2002 Lippincott Williams & Wilkins.

Key words: Balance control; Sensory enhancement; Somatosensory; Stochastic resonance

INTRODUCTION

Balance is an important functional skill that greatly influences our ability to perform activities of daily living. Diminished balance ability, often seen in older adults, poses a serious health risk due to the increased likelihood of falling. Approximately one-third of community dwelling older adults in the USA aged 65 years or over fall at least once each year, and 10–15% of these falls result in serious injury or fracture [1–3]. Falls among older adults accounted for $20.2 billion of total direct costs in 1994 and is estimated to reach $32.4 billion by the year 2020 [4].

Somatosensory deterioration, particularly in proprioception or joint-position sense, has been identified as a risk factor contributing to falls in the elderly [1,5–7]. Reductions in proprioception at the knee joint have been shown to adversely affect posture control in older adults, as indicated by increased foot center-of-pressure displacements measured on a force platform [8]. Significant reductions in joint-position sense have been noted even with normal healthy aging [9,10]. Therefore, a therapeutic intervention designed to enhance joint-position sense may prove to be beneficial to balance control and the prevention of falls in the elderly.

A promising intervention using low-level noise (electrical or mechanical) has recently been shown to improve the sensitivity of the human somatosensory system [11,12]. This work is based on the premise that low-level noise can enhance the detection and transmission of weak signals in certain nonlinear systems. This counterintuitive phenomenon, known as stochastic resonance, has been demonstrated in neurophysiological [13–17], perceptual [11,12, 18–22] and behavioral systems [23,24]. In this study, we extended the investigation of noise-based sensory enhancement to behavioral improvements in human balance control. Specifically, we tested the hypothesis that low-level electrical noise applied at the knee can enhance balance performance in older adults.

MATERIALS AND METHODS

Thirteen healthy ambulatory elderly adults (seven males and six females, age 68–79 years, mean age 72 ± 3.2 years, body mass index (BMI) 19.18–41.92 kg/m^2, BMI mean 27.80 ± 5.81 kg/m^2) volunteered to participate in this study. Subjects were randomly selected and contacted from a database of healthy older adults maintained by the Hebrew Rehabilitation Center for Aged. A self-reported medical history screened potential participants for orthopedic or neurological conditions such as Parkinson's disease, diabetes, peripheral neuropathy, stroke, disabling arthritis, uncorrected visual problems, dizziness or vertigo, use of assistive walking devices, joint injury, and joint implants. Subjects who reported these conditions were excluded from the study. The study was approved by the Boston University Institutional Review Board, and written informed consent was obtained from all subjects prior to testing. Testing took place in a laboratory setting at Boston University.

Subjects were asked to maintain balance on a single leg (their right leg) for as long as they could, up to 30 s (mean trial duration 28.7 s), with arms across their chest and with a steady forward focus (Fig. 1). Subjects were allowed to raise their arms out to the side if needed for balance; however, arm position was held constant for all trials within a single subject (only one subject employed a raised-arm strategy). Subjects maintained a small amount of flexion in their stance knee joint during the balance task and were asked to avoid locking their knee. All trials were performed with the subject standing barefoot on a force platform. Subjects performed two to three practice trials before data were recorded. The single-legged balance task was performed 16 times, with electrical noise (stimulation) applied in random order during eight of the 16 trials. Sit-down rest periods were provided every three to four trials and as requested.

During data collection for the first two subjects, it became apparent that there was a substantial risk of falling during the task. For this reason, a safety harness was used for the remaining 11 subjects. The harness was adjusted so that it was not supporting the subject's weight but would catch the subject if they completely lost balance. As only within-subject differences were assessed, the first two subjects were included in the analysis.

During the eight stimulation trials, electrical noise (Gaussian white, zero mean, s.d. = 0.05 mA) was applied through surface electrodes on the medial and lateral aspects of the subject's stance knee. The electrodes were oval (4 × 6 cm) self-adhesive gel pads (Model Platinum 896230, Axelgaard Mfg. Co., Ltd., Fallbrook, CA, USA), aligned with the longitudinal axis along the joint line formed by the femoral and tibial condyles. The electrical noise signals were generated using a personal computer running a customized LabVIEW (Version 5.1, National Instruments, Austin, TX, USA) Gaussian white noise generation program. Signals were passed through a current-controlled stimulus isolator, with a 1 mA/V conversion (Model 2200, A-M Systems, Carlsborg, WA, USA), before being applied to the subject. The noise was applied for the entire duration of a stimulation trial. The stimulation amplitude was well below the cutaneous sensation threshold of all subjects, as confirmed by a threshold measurement prior to testing. As a result, the subjects were blinded to the treatment condition.

Balance performance was characterized using a Kistler 9286 force platform (Kistler Instrument Corp., Amherst, NY, USA) to measure the displacement of the center of pressure (COP) under the subject's stance foot (Fig. 1). The force platform data were sampled at 480 Hz and digitally filtered with a zero-lag fourth-order Butterworth low-pass filter with a 5 Hz cutoff frequency. Trials lasting < 6 s were eliminated from the analysis.

The following seven sway parameters were extracted from the COP time series: the area swept out by the COP trajectory, the total cumulative path length of the COP trajectory, the mean COP radius, and the maximum excursions and standard deviations of the COP trajectory

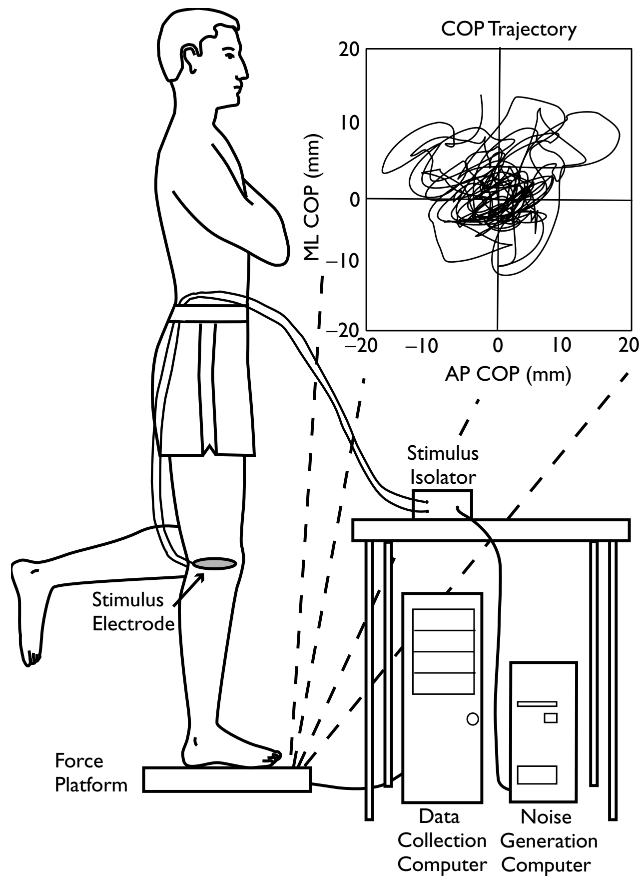

Fig. 1. Schematic representation of the experimental setup, including an example center-of-pressure (COP) trajectory for a 30 s single-legged stance trial.

in both the anteroposterior (AP) and mediolateral (ML) directions. All measures were calculated relative to the geometric center of the COP trajectory. To calculate swept area, triangular areas were formed from the geometric center and pairs of consecutive points on the COP trajectory, and the consecutive areas were then summed over the duration of the trial. To calculate path length, the distances between consecutive points on the COP trajectory were summed over the duration of the trial. Mean radius was calculated as the average of the radial lengths formed by the geometric center and each point on the COP trajectory. Maximum excursions were calculated as the maximum displacement in the respective directions (AP and ML). To calculate COP standard deviations, the standard deviation of the entire COP time series for a single trial was calculated in the AP and ML directions. The most time sensitive variables (path length and swept area) were divided by the trial duration to normalize for trials < 30 s.

COP measures were computed for each trial, and the stimulation and no stimulation condition means were calculated for each subject. Improved balance was defined as a reduction in postural sway as indicated by decreases in the COP measures. A two-tailed paired *t*-test was used to compare the stimulation and no stimulation condition

Table 1. Postural sway measures for no stimulation versus stimulation conditions.

Sway measures	No stimulation	Stimulation	Improvement (%)	p	No. of subjects improved
ML SD (mm)	4.6 ± 0.7	4.5 ± 0.7	3.8	0.04*	9/13
ML max (mm)	13.0 ± 2.2	13.1 ± 2.6	−1.1	0.71	7/13
AP SD (mm)	6.3 ± 1.3	6.1 ± 1.4	3.7	0.21	8/13
AP max (mm)	20.0 ± 5.6	19.0 ± 5.3	5.4	0.03*	9/13
Mean radius (mm)	6.9 ± 1.1	6.7 ± 1.2	3.3	0.11	9/13
Path length (mm/s)	37.1 ± 5.0	35.9 ± 5.8	3.1	0.04*	9/13
Swept area (mm^2/s)	88.8 ± 25.5	81.9 ± 24.7	7.8	0.05	9/13

Values are group means ± s.d. Positive improvement values indicate a reduction in postural sway with electrical noise.
*Significant at $p < 0.05$ level.

means for the population ($\alpha = 0.05$ was considered statistically significant).

RESULTS

Six of the seven sway parameters decreased with electrical noise (Table 1), indicating an overall improvement in balance performance in the stimulation condition. Three of the sway parameters improved significantly ($p < 0.05$), and the decrease in a fourth parameter was borderline significant ($p = 0.05$). Averaged across subjects, the application of electrical noise resulted in a 3.8% reduction in ML COP standard deviation ($p = 0.04$), a 5.4% decrease in the maximum AP COP excursion ($p = 0.03$), a 3.1% reduction in path length ($p = 0.04$), and a 7.8% decrease in swept area ($p = 0.05$). For each of these measures, nine of the 13 subjects showed improvement with electrical noise (Table 1).

DISCUSSION

This study demonstrated that imperceptible electrical noise, when applied to the knee, could enhance the balance performance of healthy elderly adults. This improvement was not limited to a particular direction of postural sway, but instead, was demonstrated in both the ML and AP directions. The fact that balance was improved in both directions when electrical noise was applied demonstrates an overall reduction in postural sway, and suggests that balance perturbations in any direction might be more easily overcome with the application of low-level noise.

The balance improvements noted in this study were in the range 3.1–7.8%. It is possible that the differences between the stimulation and no stimulation conditions could be increased by optimizing the intensity of the noise introduced during stimulation. One of the characteristics of stochastic resonance is that as the intensity of the input noise is increased, the sensitivity of a system to a weak stimulus rapidly increases to a maximum level and then slowly drops off [13–24]. The improvement in signal detection is therefore greatest at some intermediate, optimal noise intensity. In the present study, the optimal noise intensity for each subject was not determined; instead, a set noise amplitude (0.05 mA) was used.

In the present study, we measured functional improvements in balance performance in older adults when electrical noise was applied to the knee. We did not directly measure improvements in the sensitivity of sensory receptors around the knee; however, we hypothesize that the target receptors responsible for these balance improvements are those involved in knee joint proprioception. McChesney and Woollacott [8] demonstrated that knee joint proprioception in older adults is correlated to quiet-standing balance ability. Specifically, they showed that older adults with diminished knee joint-position sense had increased postural sway during undisturbed stance. One of our future research aims is to complement the current balance results with direct measures of knee joint proprioception, such as knee joint repositioning tasks, during stimulation and no stimulation conditions.

The electrical noise stimulation used in this study is likely effective in enhancing the function of the human sensorimotor system because of the electrical nature of information transfer in sensory neurons. Low-level electrical noise signals can cause small changes in receptor transmembrane potentials. This depolarization in the local membrane potential brings the neuron closer to threshold, thus making it more likely to fire an action potential in the presence of a weak signal. The electrical noise-induced depolarization when combined with graded potentials from mechanical stimuli could provide a mechanism by which normally subthreshold mechanical stimuli become detectable in the presence of electrical noise.

CONCLUSION

The present study suggests that electrical noise-based devices may be effective in improving balance control in elderly people. Possible medical devices could consist of stimulus electrodes within a wearable prosthetic. Such devices could potentially reduce the frequency and severity of falls in older adults.

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