Vibrating insoles and balance control in elderly people

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Somatosensory function declines with age, and such changes have been associated with diminished motor performance. Input noise can enhance sensory and motor function. We asked young and elderly participants to stand quietly on vibrating gel-based insoles, and calculated sway parameters and random-walk variables. In our 27 participants, application of noise resulted in a reduction in seven of eight sway parameters in young participants and all of the sway variables in elderly participants. Elderly participants showed greater improvement than young people in two variables, mediolateral range (p=0·008), and critical mean square displacement (p=0·012). Noise-based devices, such as randomly vibrating insoles, could ameliorate age-related impairments in balance control.

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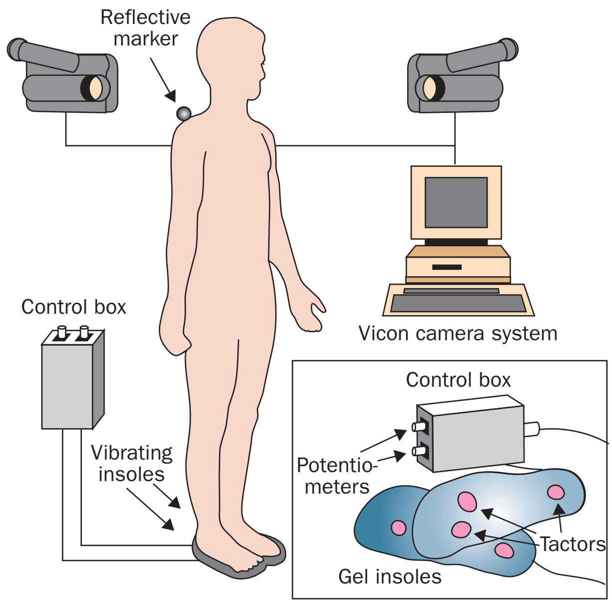
The human balance control system relies, in part, on somatosensory feedback, and in adults 65 years or older diminished somatosensation is associated with an increased likelihood of falling.[1] Input noise can enhance sensory[2] and motor[3] function, via a mechanism known as stochastic resonance. This effect is counterintuitive because noise has traditionally been thought to be detrimental to signal detection and system performance. We assessed the effects of noise input to the somatosensory system on posture control in human beings. We postulated that the postural sway of both young and elderly people during quiet standing could be substantially reduced through the application of mechanical noise to the feet via vibrating insoles.

We used posters to recruit young and elderly participants from the communities surrounding Boston University. We excluded people with neurological diseases or conditions that could affect balance or cutaneous sensation, including diabetes, vestibular diseases, foot ulcerations, numbness in the extremities, and stroke. This study was approved by the Boston University Institutional Review Board, and every participant gave written informed consent before participation.



Experimental setup
Insert box shows prototype of vibrating insoles.

During experiments, participants were asked to stand quietly on vibrating gel-based insoles (position fixed with heels separated by 8 cm, feet abducted by 40°) with their eyes closed and hands at their sides (figure).

Two insoles (about 27·9 cm×12·1 cm×1·6 cm) were moulded with a viscoelastic silicone gel (Silastic T-2 Moldmaking Rubber, Dow Corning, Midland, MI, USA). Three vibrating elements, called tactors (C-2, Engineering Acoustics, Winter Park, FL, USA), were embedded in each insole (two under the forefoot and one under the heel) to propagate vibrations to the plantar foot surface. Each insole received a noise signal, whose amplitude was set independently with potentiometers for each foot, from a small portable control box. The noise generator had a single-chip record and playback device (ISD2560P, Winbound Electronics Corporation, Taipei, Taiwan), in which a digitised uniform white noise signal, low-pass filtered to 100 Hz, was stored.

At the beginning of the testing session, participants used separate potentiometers on a control box to adjust the amplification of the noise introduced by the insoles until the stimulation could be felt only slightly under each foot. The stimulation level for the experiments was then set to 90% of this sensory threshold for each foot. Thus, the noise signals were subsensory, and participants were blinded to the stimulus condition.

To assess whole-body postural sway, displacement of the head-arm-trunk segment was measured with a reflective marker attached to the right shoulder of each participant. We used a Vicon motion analysis system (Oxford Metrics, Oxford, UK) to record the displacement of this marker during each 30 s stance trial. A plot of the mediolateral and anteroposterior shoulder displacement, called a stabilogram, was analysed for each trial. Young participants did 20 trials: ten with mechanical noise presented to the sole of each foot and ten without noise. Elderly participants did only ten trials to reduce effects of fatigue: five with mechanical noise and five without noise. The presentation sequence, noise or control, was randomised in a pair-wise fashion. All participants took a 2 min seated break midway through the experiment.

To characterise balance during quiet standing, we calculated traditional sway parameters for each trial: mean stabilogram radius (mm), the area swept by the stabilogram (mm^2), maximum sway radius (mm), and the range of the anteroposterior and mediolateral excursions (mm). We also used three random-walk variables:[3,4] the critical mean square displacement, ($\langle \Delta r^2 \rangle_c$ mm^2), the effective long-term diffusion coefficient (D_{rl} mm^2/sec), and the long-term scaling exponent (H_{rl}). Critical mean square displacement characterises the threshold at which sensory feedback mechanisms are activated by the postural control system, while the effective long-term diffusion coefficient and long-term scaling exponent capture stochastic activity and antidrift-like dynamics, respectively, of these feedback mechanisms.[3,4] We postulated that the addition of mechanical noise to the feet via the insoles would lead to a reduction in postural sway, a reduction in the sensory feedback threshold (indicated by a decrease in $\langle \Delta r^2 \rangle_c$), and a more tightly regulated control system (shown by decreases in D_{rl} and H_{rl}).

We normalised mean radius, maximum radius, anteroposterior range, and mediolateral range for each participant by dividing the variable by the height ($\times 10^{-3}$) of the reflective marker for each participant. Swept area, $\langle \Delta r^2 \rangle_c$, and D_{rl} were normalised by division of the height squared ($\times 10^{-6}$) of the reflective marker. For every variable, we calculated the mean value for the control and noise trials, respectively, for every participant. Two-way repeated-measures ANOVAs were used to assess the main effects of stimulation (control *vs* noise) and age (elderly *vs* young) on postural sway and to assess

	Young			**Elderly**			**p**		
	Control	Noise	SEMD	Control	Noise	SEMD	Age	Stimulation	Interaction
Mean radius	5·1 (0·3)	4·8 (0·2)	0·1	5·5 (0·5)	5·0 (0·5)	0·2	0·530	0·0001	0·470
Swept area	335·5 (24·5)	306·9 (20·8)	10·3	477·6 (64·0)	419·4 (56·7)	21·0	0·039	0·001	0·190
Maximum radius	12·3 (0·6)	11·7 (0·5)	0·4	13·9 (1·3)	12·8 (1·2)	0·6	0·291	0·018	0·408
Anteroposterior range	19·9 (1·0)	18·4 (0·8)	0·6	22·5 (1·9)	21·4 (1·9)	0·9	0·165	0·015	0·800
Mediolateral range	13·5 (0·7)	13·7 (0·9)	0·3	15·7 (1·8)	13·4 (1·2)	0·9	0·580	0·022	0·008
$<\Delta r^2>_c$	42·3 (3·9)	39·4 (3·5)	1·8	68·3 (10·9)	54·1 (8·1)	4·1	0·038	0·0004	0·012
$D_{rl}(s^{-1})$	2·6 (0·4)	1·7 (0·2)	0·3	2·3 (0·6)	1·8 (0·6)	0·5	0·832	0·024	0·427
H_{rl}	0·24 (0·02)	0·21 (0·02)	0·02	0·14 (0·03)	0·13 (0·03)	0·03	0·002	0·281	0·604

Data are group mean (SE). SEMD=standard error of the mean difference between the control and noise trials. p values derived from two-way repeated-measures ANOVA for the main effects of age (young *vs* elderly) and stimulus (control *vs* noise), and the interaction between age and stimulus.

Dimensionless values of the traditional and random-walk sway parameters for control and noise trials

whether there is an interaction between stimulation and age (p≤0·05).

We included 15 young (ten men and five women) and 12 elderly paticipants (eight women and four men). Mean age of young participants was 23 years (SD 2); mean body mass was 70·3 kg (13·1); and mean height 172 cm (9). In elderly participants, mean age was 73 years (3); mean body mass 69·7 kg (10·9); and mean height 161 cm (7·2). Mean sensory threshold of elderly participants was greater than that in young people (8·73 g [SD 3·16] *vs* 1·05 g [0·38], respectively; p≤0·0001).

The application of noise resulted in a reduction in seven of the eight sway parameters in young participants and all of the sway variables in elderly participants (table). The main effect of stimulation shows significant decreases in all but one parameter. We noted significant interactions between stimulation and age in mediolateral range and $<\Delta r^2>_c$ (table), which is a result of larger reductions in sway during the noise trials in the elderly than in young participants.

Subsensory mechanical noise applied to the feet of quietly standing individuals with vibrating insoles leads to enhanced feedback and reduced postural sway. Differential effects noted between young and elderly (for mediolateral range and $<\Delta r^2>_c$) indicate that elderly people gain more in motor control performance than do young people with the application of noise to the feet. Young participants might have almost optimum sensory feedback and balance control compared with elderly patients, who often have lateral postural instability[5] (characterised, in part, by mediolateral range) and raised sensory feedback thresholds.

Noise-based devices, such as randomly vibrating shoe insoles, might be effective in enhancement of performance of dynamic balance activities (eg, walking), and could enable older adults to overcome postural instability caused by age-related sensory loss.

Contributors

All authors participated in study conception and design, analysis, and interpretation of data, and critical revision of the manuscript. A A Priplata, J B Niemi, L A Lipsitz, and J J Collins drafted manuscripts. A A Priplata did statistical analysis and provided administrative support. J B Niemi and J D Harry provided administrative, technical, and material support. L A Lipsitz and J J Collins obtained funding and supervised the study.

Conflict of interest statement

J B Niemi is an employee of Afferent Corporation and holds a minority stock position. J D Harry is President and CEO of Afferent Corporation and holds a minority stock position. J J Collins chairs the Scientific Advisory Board of Afferent Corporation and holds a minority stock position.

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