Enhancing tactile sensation in older adults with electrical noise stimulation

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Older adults often suffer from diminished somatosensation stemming from age-related neuropathy. Recently, localized low-level electrical noise stimulation was shown to enhance tactile sensitivity in healthy young subjects. Here, we hypothesized that fine-touch sensitivity in older adults can be similarly improved. Semmes-Weinstein monofilaments were used to evaluate fine-touch sensitivity on the first metatarsal phalangeal joint with four electrical stimulus conditions and a null (no-noise) condition in nine healthy elderly subjects. Electrical noise stimulation resulted in a statistically significant increase in the number of detections below the null-condition detection threshold, for five of the nine subjects, as well as across the entire population. This work suggests that electrical noise-based techniques may enable people to overcome functional difficulties due to age-related sensory loss. *NeuroReport* 13:597–600 © 2002 Lippincott Williams & Wilkins.

Key words: Semmes-Weinstein monofilaments; Somatosensory; Stochastic resonance

INTRODUCTION

Loss of somatosensory input profoundly alters the effectiveness and safety of human interaction with the environment. Such deficits can result in diminished motor performance, and in elderly persons, a greater likelihood of falling [1,2]. Older adults exhibit a marked decrease in the perception of cutaneous and proprioceptive stimuli as a result of the normal aging process. This places older adults at a larger risk for the development of skin ulceration on the feet and joint dysfunction [3–5]. This sensory degradation has been associated with age-related increases in mechanoreceptor detection thresholds. Therefore, a therapeutic intervention designed to enhance the sensitivity of receptor endings may be beneficial in improving somatosensory perception, and by extension, preventing injury in individuals with age-related sensory neuropathies.

One potential therapy involves the application of either mechanical or electrical noise, to the receptor ending of sensory afferents. In information transmission tasks, the presence of noise is generally considered to be detrimental to accurate signal detection. However, it has been shown that noise can enhance the detection and transmission of weak signals in certain nonlinear systems via a mechanism known as stochastic resonance (SR) [6,7]. Numerous studies have documented SR-type effects in neurophysiological [8–13], perceptual [14–20] and behavioral systems [21–23]. We have shown previously that low-level mechanical noise can lower vibrotactile detection thresholds in healthy young subjects [14,15], as well as healthy elderly subjects, patients with stroke, and patients with diabetic neuropathy [20]. In addition, we have shown that electrical noise can be used to lower vibrotactile detection thresholds in healthy young individuals, demonstrating that SR can be a cross-modal mechanism [17].

In this paper, we extend the investigation of electrically based noise effects to healthy elderly subjects. Specifically, we examine the effects of electrical noise on fine-touch sensitivity, as measured with a widely-used clinical test, the application of Semmes-Weinstein monofilaments. We hypothesized that fine-touch sensitivity in older adults can be significantly enhanced by applying low-level electrical noise near the area of cutaneous stimulation.

MATERIALS AND METHODS

Nine healthy elderly subjects (five males and four females; age 69–82 years, mean 75 years) participated in the study. The subjects were free of neurological disease and conditions potentially affecting cutaneous sensation, including diabetes, pinched nerves, poor foot condition, numbness in the extremities, and stroke. This experiment was approved by the Boston University Charles River Campus Institutional Review Board, and informed consent was obtained from each subject prior to participation.

During the test, the subject sat in a chair, barefoot with his or her right leg extended and resting on a foam pad. Surface electrodes (Dura-Stick II self-adhesive electrodes, Model 42041, Chattanooga Group, Inc., Hixson, TN, USA, trimmed

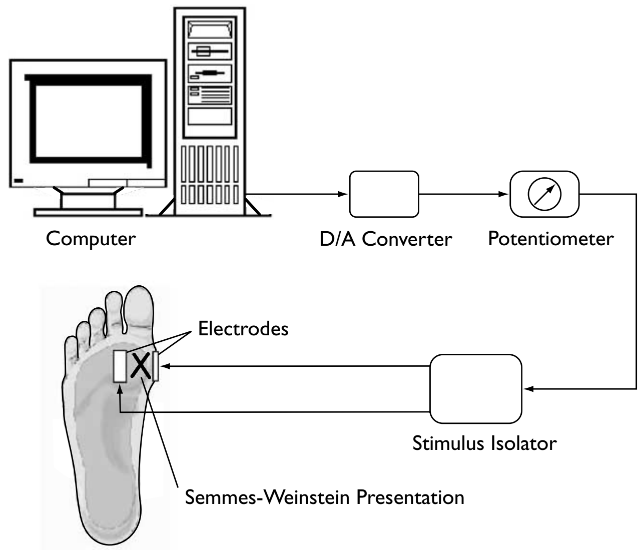

Fig. 1. A schematic representation of the experimental setup. During the tests, subjects were seated barefoot with their right leg extended. Electrodes were placed medial and lateral to the first metatarsal phalangeal (MTP) joint of the right foot. Gaussian noise signals were produced using a customized LabVIEW program, and passed through a potentiometer and a current-controlled stimulus isolator. Subjects self-selected the strength of the electrical signal by adjusting a potentiometer until the electrical noise stimulus was just below their detection level. The electrical noise stimulus was applied at 20%, 40%, 60%, and 80% of this level; a null stimulus condition was also used. Semmes-Weinstein monofilaments were pressed into the skin over the first MTP joint.

to 3/4 × 2 inches) were applied medially and laterally to the first metatarsal phalangeal (MTP) joint of the right foot (Fig. 1). An electrical noise current signal (zero mean, white noise, 1 kHz bandwidth) was applied to the foot through these electrodes. The noise signal was produced using a customized LabVIEW program (Version 5.1, National Instruments, Austin, TX, USA) and a commercial digital-to-analog converter (Model AT-A0-10, National Instruments, Austin, TX, USA). This signal was passed through a voltage divider (potentiometer) to an A-M Systems stimulus isolator (Model 2200, Carlsborg, WA, USA), operating under current control with a 1 mA/V input voltage to output current conversion.

Subjects determined their own electrical noise detection threshold by first increasing the noise signal amplitude until it was just barely noticeable and then slowly decreasing the signal amplitude until all electrical sensation disappeared. The electrical threshold setting was verified by presentation of the electrical signal at 80% and 120% of the prospective threshold level. If a subject reached the voltage limit of the experimental equipment during the threshold determination procedure without detecting the electrical noise, then this limit was used as the threshold setting.

Fine-touch sensitivity was evaluated by probing the skin over the first MTP joint using Semmes-Weinstein monofilaments [24,25]. Each monofilament imparts a known buckling force determined by its diameter. The Semmes-Weinstein test kit (Touch-Test Kit, North Coast Medical, Inc., San Jose, CA, USA) used in this study consisted of 20

Size	Force (g)	0 % Noise (Null)			20 % Noise			40 % Noise			60 % Noise			80 % Noise		
		1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
2.83	0.07	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×
3.22	0.16	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×
3.61	0.40	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×
3.84	0.60	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×
4.08	1.00	×	×	×	×	×	×	×	√	×	×	×	×	×	×	×
4.17	1.40	×	×	×	×	×	×	×	√	×	×	×	×	×	×	×
4.31	2.0	×	√	×	×	×	×	√	×	√	×	√	×	√	√	√
4.56	4.0	√	×	√	×	×	×	√	√	×	×	√	×	√	√	√
4.74	6.0	×	×	×	×	√	√	√	√	√	√	√	×	√	√	√
4.93	8.0	√	×	√	√	√	×	√	√	√	×	√	√	√	√	√
5.07	10.0	√	√	×	√	√	×	√	√	√	√	×	×	√	√	√
5.18	15.0	√	√	√	√	√	√	√	√	√	√	√	×	√	√	√

Fig. 2. An example of how the range of interest is selected. The chart shows a subject's responses to the monofilaments that were applied. A tick and a cross denote correct detections and misses, respectively. The shaded area represents the range of interest for this subject. Data are shown for Subject 4.

different monofilament diameters (hence, 20 different forces, ranging from 0.008 ∼g to 300 g).

Monofilaments were presented under five noise stimulus conditions: a null condition (no-noise stimulus), and four subthreshold noise stimulus conditions at 20%, 40%, 60%, and 80% of electrical noise threshold. The presentation order of these levels was randomized across subjects. For each noise level, tactile testing always began with the same sized monofilament (size 2.83; 0.07 g). Subjects were informed when a period of monofilament presentation began and ended, and were instructed to indicate whenever an indentation was perceived. A monofilament was presented three times with variable inter-stimulus intervals during this period. Testing within an electrical noise level continued in this manner with progressively larger monofilaments until the subject could detect all three presentations with certainty. This procedure was repeated for each noise stimulus condition.

We defined the detection rate as the ratio of the number of correct detections over the number of monofilament presentations. For each subject, the detection rate was calculated over a selected range of interest, beginning with the smallest monofilament detected at least once and extending up to, but not including, the smallest monofilament that was perceived for all three presentations in the null condition (Fig. 2). Because there were only two possible responses to each monofilament presentation, this experiment comprised a binomial process. Within each subject, we pooled the four electrical noise stimulation conditions together and compared the rate of detecting monofilament presentations with electrical noise against the detection rate from the null condition. We thus calculated two detection rates for each subject: (1) a null condition detection rate from the null presentations, and (2) an electrical noise condition detection rate from the pooled four subthreshold noise stimulation conditions.

Even though each monofilament did not have an equal probability of detection because larger monofilaments have a greater chance of being detected, each monofilament size was presented an equal number of times for each subject and stimulus condition. Therefore, it is valid to use the binomial distribution to analyze these data. We used the binomial distribution to assess the likelihood of observing the detection rate from the electrical noise condition within each subject, with the null detection rate serving as the probability of a detection. A paired *t*-test was used to evaluate differences in the detection rate between the two conditions across the population.

RESULTS

When we used the binomial distribution to look at individual performance, we found that seven of the nine subjects exhibited a higher detection rate with electrical noise than in the null condition, while an eighth subject showed virtually no change and the ninth subject decreased in sensitivity (Fig. 3). The improvement with electrical noise application was statistically significant in five of the nine subjects. We performed a two-tailed paired *t*-test on the detection rates from the null condition and the electrical noise condition and found that the increase in sensitivity with electrical noise was statistically significant ($p < 0.01$) for the population.

DISCUSSION

In this study, we showed that low-level electrical noise can significantly improve fine-touch sensitivity on the plantar surface of the foot in the elderly using Semmes-Weinstein monofilaments. An earlier study demonstrated that reduced vibrotactile sensitivity in older adults can be significantly improved with input mechanical noise [20]. The authors described two possible mechanisms to account for this effect: (1) vibratory noise added mechanical energy to the vibrotactile stimulus, enhancing the transmission of vibration through dermal tissues, and (2) the vibratory noise directly acted upon receptor endings. In this study, the mechanical noise stimulus was replaced with an electrical noise stimulus and the site of the noise stimulation was spatially separated from the location of the applied test stimulus. The results from our study indicate that electrical noise sensitizes mechanoreceptors in the target skin area, making normally subthreshold stimuli detectable. We suspect this occurs because the electrical noise signal affects the local field potential around the mechanoreceptors, rendering them more likely to fire an action potential in the case of enhanced sensitivity.

A confounding factor for the present study is that the electrical noise may not have been optimal for each individual. It is possible that the optimal electrical noise level for some subjects is above the level of cutaneous electrical detection. Suprathreshold electrical stimuli were not presented in this study, to ensure that the subjects were blind to the stimulus condition. Cutaneous electrical sensation, electrical impedance of dermal tissues, and stimulus isolator limitations may all contribute to varied electrical stimulation conditions for each subject. As such, we decided to pool the four subthreshold noise stimulus conditions together and use the binomial distribution to determine the likelihood of observing at least as high a detection rate when electrical noise was applied, given the detection rate of the null condition. In so doing, we found a significant increase in fine-touch sensitivity during the electrical noise condition when data from all subjects were pooled. In addition, we found that electrical noise significantly enhanced sensitivity in five of the nine subjects. It is possible that if other levels of electrical noise were applied, even more subjects would have exhibited enhanced sensitivity.

This work suggests that electrical noise-based techniques and devices, such as electrode-lined socks or gloves, may enable people to overcome age-related sensory loss. It is also possible that such techniques and devices could provide some level of protective sensation to individuals with disease-related sensory loss, such as patients with diabetic neuropathy. Future studies may determine a way to administer optimal electrical noise stimulation in order to maximize sensory enhancement benefits within an individual.

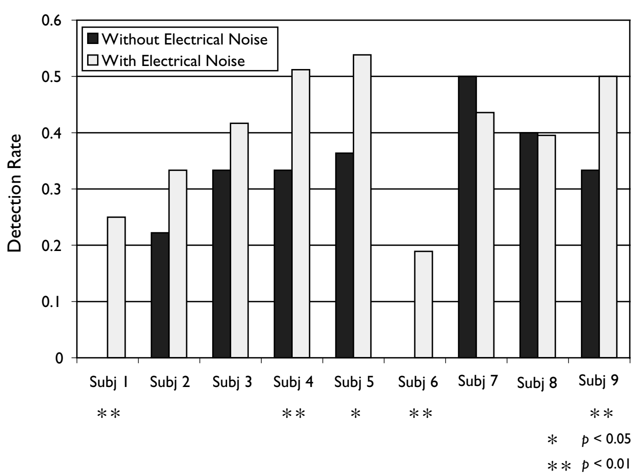

Fig. 3. A comparison between the detection rate without (null) and with the application of electrical noise for each subject. Statistically significant differences respectively) between the null and electrical noise conditions determined by the binomial distribution $*p < 0.05$; $**p < 0.01$, respectively. For Subjects 1 and 6, there is no bar shown for the null condition because in these cases the subjects did not detect any monofilament presentations below the null-condition detection threshold.

CONCLUSION

In this study, we showed that fine-touch sensitivity in older adults can be significantly improved with input electrical noise. Specifically, we demonstrated in a sample of healthy elderly subjects that the application of subthreshold electrical noise improved the likelihood of detecting Semmes-Weinstein monofilament presentations on the plantar surface of the foot at normally subthreshold force levels. This work suggests that electrical noise-based techniques and devices may enable people to overcome functional difficulties due to age-related sensory loss.

REFERENCES

1. Lord SR, Clark RD and Webster IW. *J Gerontol* **46**, M69–M76 (1991).
2. Tanaka T, Hashimoto N, Noriyasu S *et al*. *Phys Occup Ther Geriatr* **13**, 1–16 (1995).
3. Kusoffsky A, Wadell I and Nilsson BY. *Scand J Rehab Med* **14**, 27–32 (1982).
4. Leo KC and Soderberg GC. *Phys Ther* **61**, 1433–1437 (1982).
5. Geischeder GA, Bolanowski SJ, Verillo RT *et al*. *Somatosens Mot Res* **11**, 345–357 (1994).
6. Moss F, Pierson D and O'Gorman D. *Int J Bifurc Chaos* **4**, 1383–1397 (1994).
7. Wiesenfeld K and Moss F. *Nature* **373**, 33–36 (1995).
8. Douglass JK, Wilkens L, Pantazelou E *et al*. *Nature* **365**, 337–340 (1993).
9. Collins JJ, Imhoff TT and Grigg P. *J Neurophysiol* **76**, 642–645 (1996).
10. Cordo P, Inglis JT, Verschueren S *et al*. *Nature* **383**, 769–770 (1996).
11. Levin JE and Miller JP. *Nature* **380**, 165–168 (1996).
12. Gluckman BJ, Netoff TI, Neel EJ *et al*. *Phys Rev Lett* **77**, 4098–4101 (1999).
13. Stacey WC and Durand DM. *J Neurophysiol* **83**, 1394–1402 (2000).
14. Collins JJ, Imhoff TT and Grigg P. *Nature* **383**, 770 (1996).
15. Collins JJ, Imhoff TT and Grigg P. *Phys Rev E* **56**, 923–926 (1997).
16. Simonotto E, Rani M, Seife C *et al*. *Phys Rev Lett* **78**, 1186–1189 (1997).
17. Richardson KA, Imhoff TT, Grigg P *et al*. *Chaos* **8**, 599–603 (1998).
18. Piana M, Canfora M and Riani M. *Phys Rev E* **62**, 1104–1109 (2000).
19. Zeng FG, Fu QJ and Morse R. *Brain Res* **869**, 251–255 (2000).
20. Liu W, Lipsitz LA, Montero-Odasso M *et al*. *Arch Phys Med Rehab*, in press.
21. Russell DF, Wilkens LA and Moss F. *Nature* **402**, 291–294 (1999).
22. Hidaka I, Nozaki D and Yamamoto Y. *Phys Rev Lett* **85**, 3740–3743 (2000).
23. Hidaka I, Ando S, Shigematsu H *et al*. *J Neurophysiol* **86**, 559–564 (2001).
24. Bell-Krotoski J and Tomancik E. *J Hand Surg (Am)* **12**, 155–161 (1987).
25. Bell-Krotoski JA, Fess EE, Figarola JH *et al*. *J Hand Ther* **8**, 155–162 (1995).

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