Noise-enhanced postural stability in subjects with functional ankle instability

Scott E Ross

Br J Sports Med 2007;41:656–659. doi: 10.1136/bjsm.2006.032912

Objective: To examine the effects of stochastic resonance (SR) stimulation on the postural stability of subjects with functional ankle instability (FAI).

Design: Experimental research design.

Setting: Sports medicine research laboratory.

Participants: 12 subjects with FAI who reported a history of recurrent ankle sprains and “giving way” sensations at the ankle.

Interventions: Subjects performed 20 s single-leg balance tests under SR stimulation at 0.05 mA and 0.01 mA and under control conditions. Testing order was randomised. Stimulators that delivered subsensory stimulation to ankle muscles and ligaments were worn. Subjects were blinded to the test conditions, as SR stimulation was subsensory and stimulators were turned off during the control condition.

Main outcome measures: Anterior/posterior and medial/lateral centre-of-pressure velocities (COPVs) were combined to form a resultant vector (COPV-R). The COPV-R differences between the optimal SR stimulation and control conditions were analysed. Optimal SR stimulation was defined as the SR stimulation input intensity level (0.05 mA or 0.01 mA) that produced the greatest percentage improvement in postural stability compared with the control condition. Slower velocities indicated enhanced postural stability.

Results: The optimal input intensity was 0.05 mA for nine subjects and 0.01 mA for the other three. The optimal SR stimulation significantly ($p < 0.05$) improved COPV-R compared with the control condition (6.60 (1.06) vs 7.20 (1.03) cm/s; mean (SD)).

Conclusion: SR stimulation may enhance signal detection of sensorimotor signals associated with postural stability. This result has clinical relevance as improvements in postural instability associated with FAI may decrease ankle sprain injury.

Correspondence to:
Dr S E Ross, Department of
Health and Human
Performance, Virginia
Commonwealth University,
1015 W Main St, PO box
842020, Richmond, VA
23284-2020, USA; seross@
vcu.edu

Accepted 6 March 2007
Published Online First
5 June 2007

Ankle sprains are common injuries that occur during physical activity, and a history of ankle sprain has been found to correlate with an increased risk of recurrent ankle sprain.^{1–4} Functional ankle instability (FAI) is a pathology defined by sensations of instability at the ankle and recurrent ankle sprains, and the incidence in physically active people who have had an ankle sprain injury has been estimated to be 30–78%.^{1–5} The underlying cause of FAI has not been identified despite its common occurrence in the physically active. Possible causal factors include mechanical instability, sensorimotor system deficits and strength deficits.^{6–13}

Postural stability impairments have been proposed as a causal factor of ankle sprains, and poor postural stability has been found to be associated with FAI.^{11–12, 14–18} Researchers have speculated that sensorimotor system deficits correlated with FAI are responsible for impairing postural stability.^{11–12} Coordination and balance rehabilitation for FAI have been successful in improving postural stability and decreasing the incidence of ankle sprain.^{14–16, 19} The prophylactic effect of rehabilitation, however, generally takes 4–8 weeks, and sports medicine clinicians have contended that recurrent ankle sprains are more likely when patients with FAI return to activity before achieving the full prophylactic effect of rehabilitation.^{3, 5, 14–16} Therapy that improves joint stability before full recovery may help to decrease ankle sprain injury in patients returning to physical activity.

Random subsensory electrical noise stimulation may be a useful adjunct therapy to rehabilitation that enhances ankle stability through a phenomenon known as stochastic resonance (SR). Subsensory electrical noise administered at a specific input intensity is thought to improve neural communication.²⁰

SR stimulation in the form of random subsensory electrical noise has been reported to cause subthreshold sensorimotor signals to exceed threshold, allowing weak sensorimotor signals to become detectable.²⁰ However, SR stimulation will only enhance sensorimotor signal detection up to a particular input intensity; it then worsens as input intensity increases.^{20–21}

SR stimulation is thought to enhance the detection of sensorimotor signals related to postural control, as SR stimulation applied during balance testing has been found to improve postural stability in healthy and older subjects.^{21–24} It may also enhance postural stability deficits associated with FAI. As people with FAI have problems balancing on one leg, the use of SR stimulation to improve sensorimotor function may allow them to perform single-leg balance exercises that they may not otherwise be able to perform effectively during ankle rehabilitation. Thus, this treatment has potential for enhancing the rehabilitation of FAI. A recent study²⁵ found that SR stimulation used during a 6-week balance training programme facilitated rehabilitation more than balance training alone in subjects with FAI. Thus, SR stimulation has been shown to improve postural stability over several weeks of training. However, the immediate effect of SR stimulation on postural instability associated with FAI is not known. Improving postural stability in physically active people with FAI through the use of SR stimulation may help to increase ankle joint stability and decrease the incidence of recurrent ankle sprain. Therefore, the purpose of this study was to determine the

Abbreviations: COPV, centre-of-pressure velocity; COPV-R, centre-of-pressure velocity resultant; FAI, functional ankle instability; SR, stochastic resonance

effects of SR stimulation on the postural stability of subjects with FAI.

METHODS

Subjects

Six male and six female physically active people (mean (SD) weight 71 (16) kg, height 173 (10) cm and age 22 (2) years) who reported a history of recurrent ankle sprains and "giving way" sensations at the ankle participated in this study. They all participated in physical activity for a minimum of 3 h/week. Ten of the 12 subjects had also participated in a coordination training investigation.²⁵ The subjects read and signed a consent form approved by the Committee for the Protection of the Rights of Human Subjects before participation.

Criteria for defining FAI have been described previously.^{25–27} In short, subjects had a history of one ankle sprain requiring immobilisation and a minimum of two additional sprains that did not require immobilisation in the year preceding participation in this study. They reported signs and symptoms of an acute ankle sprain injury with each sprain.^{25–27} In addition, they had to report a minimum of two "giving way" sensations in the preceding year. Subjects reported a mean (SD) of 3 (1) ankle sprains (range 2–5) and 5 (4) "giving way" sensations (range 2–15) in the 12 months preceding participation in the study. Positive anterior drawer and talar tilt tests were present in 75% and 92% of subjects, respectively.

Potential subjects with FAI were excluded if they had sustained an ankle sprain injury in the 6 weeks preceding participation in the study. Exclusion criteria also included a history of lower extremity fractures, knee injuries and hip injuries. Lastly, potential subjects with FAI with visual impairments that affected their balance, vestibular deficits or neurological dysfunctions were also excluded.

Single-leg stance test

Subjects were shoeless during the single-leg stance test. The foot of the test leg was placed in a comfortable position during the test. This foot position was kept constant for all test conditions. While standing on one leg, subjects kept their eyes closed, with hands on hips and the non-weight bearing leg in a slightly flexed position.²⁶ They were instructed to remain as still as possible for 20 s while standing on the test leg on the force plate. They had one practice trial for 20 s before testing.

Single-leg stance tests were performed under SR stimulation and control (no SR stimulation) conditions. SR stimulator units (Afferent Corp, Providence, Rhode Island, USA) with surface electrodes (2×2 cm) and self-adhesive gel pads (model Platinum 896230; Axelgaard, Fallbrook, California, USA) were placed on the skin over the muscle bellies of the lateral soleus, peroneus longus, tibialis anterior, anterior talofibular ligament and deltoid ligament during single-leg stance tests. SR stimulation was delivered via subsensory electrical noise (Gaussian white noise, zero mean, SD = 0.05 mA or sd = 0.01 mA) to ankle muscles and ligaments. The noise amplitude of 0.05 mA was selected because it has been used in previous balance studies, and has improved postural stability in older patients with associated sensorimotor impairments.^{24–25} This amplitude was therefore a logical choice as a therapeutic intensity to improve postural stability because sensorimotor deficits have also been associated with FAI.^{6–10} However, it has also been reported to have no effect on certain postural stability measures.²⁴ An input intensity of 0.01 mA was used to examine the effects of a lower amplitude, as too high an amplitude has been implicated in negating improvements associated with SR stimulation.^{20–21}

Subjects performed four trials for each test condition. A randomised block design was used to determine order of testing

for SR and control conditions. Subjects were blinded to test conditions, as SR stimulation was subsensory and stimulators were turned off for the control condition.

Data collection

A force plate (Bertec Corp, Columbus, Ohio, USA) collected analogue data during the single-leg stance test at a sampling rate of 180 Hz.²⁶ Analogue signals were amplified by a factor of 2 and passed through a BNC adapter chassis (model number PCI-MIO-16E-1; National Instruments, Austin, Texas, USA) that was interfaced with an analogue-to-digital board in a PC. Digital data were converted into ground reaction force vectors, moments and location of the centre-of-pressure with MotionSoft Balance Assessment computer software package V.2.0 (MotionSoft Inc, Chapel Hill, North Carolina, USA). A second-order recursive low-pass Butterworth digital filter with an estimated optimum cut-off frequency of 12.53 Hz filtered the data.²⁶ Anterior/posterior and medial/lateral centre-of-pressure velocities (COPVs) were combined to form a resultant vector (COPV-R). Slower COPV-R indicates enhanced postural stability.

Statistical analysis

The mean of four trials for each test condition was used for data analysis. Percentage differences were calculated between SR stimulation and control conditions to determine the optimal SR stimulation. The optimal SR stimulation was defined as the SR stimulation input intensity level (0.05 mA or 0.01 mA) that produced the greatest percentage improvement in postural stability compared with the control condition. A paired-samples t test was used to analyse mean differences between the optimal SR stimulation condition and control condition. Effect size (ES) was calculated using Cohen's effect size index (d).²⁸ SPSS V.13.0 (SPSS Inc, Chicago, Illinois, USA) was used for statistical analysis. α was set at $p < 0.05$.

RESULTS

Table 1 presents percentage differences between SR stimulation and control conditions for each subject. The optimal input intensity was 0.05 mA for nine subjects and 0.01 mA for the other three. The postural stability of subject 12 was not improved with either level of stimulation compared with the control condition. However, the COPV-R value for the 0.01 mA input intensity for this subject was used in data analysis. The

Table 1 Percentage difference between stochastic resonance stimulation (at 0.05 and 0.01 mA) and control conditions in subjects with functional ankle instability

Subject	Difference in COPV-R (%)	
	0.05 mA	0.01 mA
1	3.89*	3.43
2	19.63*	16.73
3	–27.71	8.31*
4	–3.91	10.10*
5	9.88*	–14.30
6	8.23*	4.19
7	12.94*	5.76
8	11.92*	9.15
9	4.16*	–3.14
10	9.50*	–3.39
11	4.98*	–3.44
12	–14.09	–3.31*

COPV-R, centre-of-pressure velocity resultant.

Negative values indicate impairment with stochastic resonance stimulation.

Positive values indicate improvement with stochastic resonance stimulation.

*Indicates the optimal stimulation level used in the paired-samples t test comparison.

optimal SR stimulation significantly ($t(11) = 5.17$, $p < 0.01$, $ES = 0.56$) improved COPV-R by 8.29% over the control condition (6.60 (1.06) vs 7.20 (1.03) cm/s; mean (SD)).

DISCUSSION

The most important finding of this study is that the optimal SR stimulation improved postural stability compared with the control condition, suggesting that SR stimulation may enhance signal detection of sensorimotor signals associated with postural stability. These results have clinical relevance, as improvements in postural instability associated with FAI have been reported to enhance ankle joint stability and reduce the incidence of ankle sprain.^{14 16 25} Therefore, SR stimulation may help to decrease recurrent ankle sprains in physically active people with FAI. As this study examined short-term improvements, SR stimulation should be applied during balance activities to enhance postural stability. Clinically, the integration of SR stimulation technology into shoe insoles or ankle braces may improve postural stability during physical activity and ankle rehabilitation.

The pathways whereby SR stimulation improves signal detection are not fully understood. It has been suggested that SR stimulation may bring mechanoreceptors closer to the threshold by altering ion permeability, leading to fluctuations in transmembrane potentials.^{24 29 30} The chance of an action potential being generated from a weak sensorimotor signal might then be increased because the mechanoreceptor is brought closer to the threshold with SR stimulation.^{24 29 30} SR stimulation has been implicated in depolarising cutaneous, muscle spindle and Golgi tendon organ mechanoreceptors.^{20 30 31} Furthermore, SR stimulation has been shown to improve muscle spindle firing to a passive stretch of the wrist before and after deactivation of the cutaneous fusimotor system with an anaesthetic block in a single subject, suggesting that muscle spindle mechanoreceptors can be sensitised by SR stimulation to detect signals related to a passive stretch.²⁰ In the present study, weak signals related to postural control may have become detectable as a result of SR stimulation bringing muscle spindles and/or Golgi tendon organs of the lower leg and ankle closer to the threshold in subjects with FAI. Sensitising muscle spindles and Golgi tendon organs with SR stimulation is probably one neurological mechanism that improved postural stability. Future research should examine neurological mechanisms for processing SR stimulation in subjects with FAI.

The SR stimulation used in this study improved postural stability by 8.29% over the control condition. Gravelle *et al*²⁴ reported that SR stimulation improved anterior/posterior and medial/lateral postural stability by 3.1–7.8% compared with test conditions without SR stimulation in healthy and older subjects. It has been found that SR characteristics in the human nervous system can be maximised at a specific input intensity of noise.^{20 21 24} Furthermore, Gravelle *et al*²⁴ suggested that the effects of SR stimulation may be increased by optimising the intensity of the random subsensory noise. Priplata *et al*²¹ also reported that postural stability improved in healthy and older subjects as the input intensity of SR stimulation was increased to a particular intensity. It then worsened as input intensities continued to increase beyond this level.²¹ Thus, improvements in postural stability may be maximised at an input intensity other than the optimal used in the present investigation.

The optimal input intensity of SR stimulation was probably appropriate for improving postural stability in 92% (11/12) of our subjects with FAI. Percentage change data indicate that optimisation of SR stimulation was necessary to improve postural stability. Postural stability was improved with both

input intensities in five subjects. The input intensity of 0.05 mA was not appropriate for two subjects, but 0.01 mA did improve stability for them. Conversely, 0.01 mA was not appropriate for four subjects, but 0.05 mA worked well for them. Postural stability was not improved in subject 12 with either intensity. Clearly, SR stimulation should be individually optimised to improve postural instability in patients with FAI. This investigation only examined two input intensities, and postural stability may have improved to a greater degree at another intensity. Future research should determine the optimal input intensity for maximising improvements in postural stability in subjects with FAI.

The results of this investigation should be interpreted with caution. Two different input intensities were used to optimise SR stimulation effects on postural stability. However, they may not represent the true optimal input intensity for enhancing stability. The logic for using 0.01 mA was that 0.05 mA may create too much noise to enhance stability. If 0.05 mA was not too high, a third intensity set higher than 0.05 mA may have improved postural stability to a greater extent than either input intensity used in this study. A third intensity should have been analysed to clarify this. Furthermore, random error associated with the group design possibly masked the true effects of SR stimulation on postural stability, as this treatment did not improve postural stability in some subjects as much as in others. A single-subject design that has a variety of input intensities for optimising SR stimulation is probably the correct design for future investigations of the effects of SR stimulation on postural stability. Interestingly, however, the effect size associated with improvements in postural stability with SR stimulation was 0.56, which is greater than effect sizes in the literature associated with improvements in postural stability from balance training (0.41–0.48) or bracing (0.11–0.44) in subjects with FAI.^{14 32} The medium effect size in this investigation is promising, and the use of SR stimulation as a treatment to improve balance warrants further investigation.

Additional evidence for the role of SR stimulation in improving signal detection and postural stability has been reported.^{25 33 34} Waddington and Adams³⁴ examined the use of

What is already known on this topic

- Stochastic resonance stimulation in the form of random subsensory electrical noise can enhance the detection of weak sensorimotor signals.
- Postural stability in older people is improved with SR stimulation administered during balance tests.
- A 6-week balance training programme with SR stimulation enhanced dynamic postural stability in subjects with FAI.

What this study adds

- This study investigated short-term postural stability improvements associated with SR stimulation administered during a single-leg balance test.
- Postural instabilities associated with FAI can be improved with an optimal noise intensity level of SR stimulation.
- Noise intensity levels of SR stimulation should be optimised before application to improve balance.

textured insoles in detecting ankle inversion motion. They reported that ankle inversion motions were better discriminated by healthy soccer (football) players when barefoot or using textured insoles than when using smooth (regular) insoles.³⁴ Davids *et al*³³ suggested that the noise provided by textured insoles caused an SR phenomenon that allowed subjects to detect differences in ankle inversion motion more effectively than with smooth insoles. In addition, SR stimulation used during a 6-week balance training programme facilitated rehabilitation in subjects with FAI by enhancing dynamic postural stability earlier and to a greater extent than did balance training alone after 2 and 4 weeks of training, respectively.²⁵ Whereas the results of the latter study suggest that improvements in postural stability with SR stimulation take 2–4 weeks, the results of the current study suggest that postural stability can be improved immediately with the application of SR stimulation in most subjects.

SR stimulation could be used as an adjunct therapy for rehabilitating postural instabilities associated with FAI. Although balance training has been found to be effective in improving postural instability associated with FAI after several weeks of training,^{14–16, 25} SR stimulation at an appropriate input intensity could be used to improve postural stability immediately. This treatment would be particularly useful for patients with FAI who have problems balancing on one leg during rehabilitation exercises. SR stimulation should allow them to perform single-leg balance exercises effectively, potentially facilitating and enhancing ankle rehabilitation. Improving postural stability with SR stimulation may help to decrease recurrent ankle sprain injury associated with FAI. Future research should prospectively examine the effects of SR stimulation on the incidence of ankle sprains in physically active people.

ACKNOWLEDGEMENTS

Stimulation units were provided by Dr Jason D Harry and James B Niemi of the Afferent Corporation (Providence, Rhode Island, USA).

Competing interests: None.

REFERENCES

- McKay G, Goldie P, Payne W, *et al*. Ankle injuries in basketball: injury rate and risk factors. *Br J Sports Med* 2001;**35**:103–8.
- Yeung M, Chan K, So C, *et al*. An epidemiological survey on ankle sprain. *Br J Sports Med* 1994;**28**:112–16.
- Bahr R, Karlens R, Lian O, *et al*. Incidence and mechanisms of acute ankle inversion injuries in volleyball: a retrospective cohort study. *Am J Sports Med* 1994;**22**:595–600.
- Verhagen E, van der Beek A, Bouter L, *et al*. A one season prospective cohort study of volleyball injuries. *Br J Sports Med* 2004;**38**:477–81.
- Tropp H. Commentary: functional ankle instability revisited. *J Athl Train* 2002;**37**:512–15.
- Docherty C, Arnold B, Hurwitz S. Contralateral force sense deficits are related to the presence of functional ankle instability. *J Orthop Res* 2006;**24**:1412–19.
- Arnold B, Docherty C. Low-load eversion force sense, self-reported ankle instability, and frequency of giving way. *J Athl Train* 2006;**41**:233–8.
- Willems T, Witvrouw E, Verstuyft J, *et al*. Proprioception and muscle strength in subjects with a history of ankle sprains and chronic instability. *J Athl Train* 2002;**37**:487–93.
- Refshauge K, Kilbreath S, Raymond J. Deficits in detection of inversion and eversion movements among subjects with recurrent ankle sprains. *J Orthop Sports Phys Ther* 2003;**33**:166–76.
- Ryan L. Mechanical stability, muscle strength and proprioception in the functionally unstable ankle. *Aust Physiother* 1994;**40**:41–7.
- Tropp H. Pronator muscle weakness in functional instability of the ankle joint. *Int J Sports Med* 1986;**7**:291–4.
- Konradsen L, Ravn J. Prolonged peroneal reaction time in ankle instability. *Int J Sports Med* 1991;**12**:290–2.
- Hubbard T, Kaminski T, Vander Griend R, *et al*. Quantitative assessment of mechanical laxity in the functionally unstable ankle. *Med Sci Sports Exerc* 2004;**36**:760–6.
- Eils E, Rosenbaum D. A multi-station proprioception exercise program in patients with ankle instability. *Med Sci Sports Exerc* 2001;**33**:1991–8.
- Gauffin H, Tropp H, Odenrick P. Effect of ankle disk training on postural control in patients with functional instability of the ankle joint. *Int J Sports Med* 1988;**9**:141–4.
- Rozzi S, Lephart S, Sterner R, *et al*. Balance training for persons with functionally unstable ankles. *J Orthop Sports Phys Ther* 1999;**29**:478–86.
- Tropp H, Ekstrand J, Gillquist J. Stabilometry in functional instability of the ankle and its value in predicting injury. *Med Sci Sports Exerc* 1984;**16**:64–6.
- McGuine T, Greene J, Best T, *et al*. Balance as a predictor of ankle injuries in high school basketball players. *Clin J Sport Med* 2000;**10**:239–44.
- Tropp H, Askling C, Gillquist J. Prevention of ankle sprains. *Am J Sports Med* 1985;**13**:259–62.
- Cordo P, Inglis J, Verschueren S, *et al*. Noise in human spindles. *Nature* 1996;**383**:769–70.
- Priplata A, Patriitie B, Rosengarten A, *et al*. Enhancing human balance control by applying random vibrations to the ankle tendons. *Med Sci Sports Exerc* 2006;**38**:S440.
- Priplata A, Niemi J, Salen M, *et al*. Noise-enhanced human balance control. *Phys Rev Lett* 2002;**89**:238101–1–238101–4.
- Priplata A, Niemi J, Harry J, *et al*. Vibrating insoles and balance control in elderly people. *Lancet* 2003;**362**:1123–4.
- Gravelle D, Laughton C, Dhruv N, *et al*. Noise-enhanced balance control in older adults. *Neuroreport* 2002;**13**:1–4.
- Ross S, Guskiewicz K. Effect of coordination training with and without stochastic resonance stimulation on dynamic postural stability of subjects with functional ankle instability and subjects with stable ankles. *Clin J Sport Med* 2006;**16**:323–8.
- Ross S, Guskiewicz K. Examination of static and dynamic postural stability in individuals with functionally stable and unstable ankles. *Clin J Sport Med* 2004;**14**:332–8.
- Ross S, Guskiewicz K. Single-leg jump-landing stabilization times in subjects with functionally unstable ankles. *J Athl Train* 2005;**40**:298–304.
- Cohen J. The t test for means. In: *Statistical power analysis for the behavioral sciences*. 2nd edn. Hillsdale, NJ: Lawrence Erlbaum Associates, Publishers, 1988:41.
- Priplata A, Patriitie B, *et al*. Noise-enhanced balance control in patients with diabetes and patients with stroke. *Ann Neurol* 2006;**59**:4–12.
- Richardson K, Imhoff T, Grigg P. Using electrical noise to enhance the ability of humans to detect subthreshold mechanical cutaneous stimuli. *Chaos* 1998;**8**:599–603.
- Fallon J, Carr R, Morgan D. Stochastic resonance in muscle receptors. *J Neurophysiol* 2004;**91**:2429–36.
- Baier M, Hopf T. Ankle orthoses effect on single-limb standing balance in athletes with functional ankle instability. *Arch Phys Med Rehabil* 1998;**79**:939–44.
- Davids K, Shuttleworth R, Button C, *et al*. "Essential noise"-enhancing variability of informational constraints benefits movement control: a comment on Waddington and Adams (2003). *Br J Sports Med* 2004;**38**:601–5.
- Waddington G, Adams R. Football boot insoles and sensitivity to extent of ankle inversion movement. *Br J Sports Med* 2003;**37**:170–5.

COMMENTARY

It is already known that applying SR to the sensorimotor system in ageing populations can enhance functional behaviours such as postural stability. This study proposes that SR can be used as an adjunct therapy in rehabilitation and sports medicine programmes. However, more work is needed to confirm the exact mechanism of application. Is stimulation of the musculature of the lower leg responsible for transmitting the random noise in this study? Or is the proprioceptive system the actual conduit? The "optimal intensities" in SR applications also need to be clarified. In clinical contexts, a group design cannot answer that question, as levels of error variance in the data may mask observed effects. A more useful approach is a multiple-baseline, single-participant design¹ in which "optimal" levels of noise intensity are generated for each individual to assess behavioural effects. As a first step, in this study, it would have been interesting to understand how many participants experienced an improvement in postural stability between control and experimental treatment conditions.

Keith W Davids

Queensland University of Technology, School of Human Movement Studies, Brisbane, Queensland, Australia; k.davids@qut.edu.au

REFERENCE

- Bates BT. Single-participant methodology: an alternative approach. *Med Sci Sport Exerc* 1996;**28**:631–8.