Original article

Noise-enhanced dynamic single leg balance in subjects with functional ankle instability

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Abstract

Background: Stochastic resonance stimulation (SRS) transmits subsensory electrical Gaussian white noise into the body to enhance sensorimotor function. This therapy has improved static single leg balance in subjects with functional ankle instability. However, the effect of this stimulation on dynamic single leg balance is not known. Improvements in dynamic single leg balance with SRS may have implications for enhancing functional rehabilitation for ankle instability. Thus, the purpose of this study was to determine the effects of SRS on dynamic single leg balance in subjects with functional ankle instability.

Methods: This study was an experimental research design and data were collected in a sports medicine research laboratory. Twelve subjects with functional ankle instability (69 ± 15 kg; 173 ± 10 cm; 21 ± 2 years) reported a history of ankle sprains and instability at the ankle with physical activity. A single leg jump-landing test was used to assess dynamic balance. Subjects were required to jump between 50% and 55% of the maximal vertical jump height, land on a single leg atop a force plate, and stabilize as quickly as possible. Jump-landing tests were performed with and without SRS. Three trials were performed for each treatment condition (SRS and control). A randomized block design was used to determine test order. Anterior/posterior and medial/lateral time-to-stabilization were computed to assess dynamic balance. Lesser time indicated better stability. One-tailed paired samples t tests were used for analysis (a ≤ 0.05).

Results: SRS improved anterior/posterior time-to-stabilization (stochastic resonance = 1.32 ± 0.31 s, control = 1.74 ± 0.80 s, p = 0.03), but did not enhance medial/lateral time-to-stabilization (stochastic resonance = 1.95 ± 0.40 s, control = 1.92 ± 0.48 s, p = 0.07).

Conclusion: Clinicians might use SRS to facilitate balance improvements with sagittal plane dynamic single leg balance exercises that patients may not be able to perform otherwise.

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1. Introduction

Ankle sprains are common injuries that occur during physical activity, and this pathology has been linked to health impairments. Functional ankle instability (FAI) often occurs following sprains, causing sensations of instability at the ankle and recurrent ankle sprains. The causal factors of FAI are not fully understood, but researchers indicate that deficits in sensorimotor function, eversion strength, and balance are associated with this injury. These factors are not mutually exclusive and may be linked in a way that allows one impairment to exacerbate another. For example, researchers have...
identified sensorimotor impairments associated with FAI as being one source of poor balance. Interestingly, balance deficits are important to identify because these impairments have been indicative of ankle sprains. As a result of balance deficits association with FAI, clinicians include both sensorimotor and balance exercises in rehabilitation protocols to prevent recurrent sprains and to improve ankle stability.

Therapeutic exercises or devices that facilitate balance improvements may have implications for enhancing rehabilitation by allowing patients to perform exercises earlier in the healing process. A complimentary therapy known as stochastic resonance stimulation (SRS) can facilitate balance improvements immediately or more quickly than rehabilitation alone. SRS introduces subsensory Gaussian white noise (either electrical or mechanical) through the skin to enhance the ability of mechanoreceptors to detect and transmit weak sensory signals. This noise can add constructively to subthreshold signals to make detectable signals and can change ion permeability to bring membrane potentials closer to threshold. Evidence indicates that muscle spindles can be affected by SRS, allowing these mechanoreceptors to detectafferent signals and, in turn, increase efferent output. As a result, researchers have investigated the treatment effects of SRS on balance because muscle spindles are crucial for initiating reflexive muscle contractions that positively impact postural stability.

SRS has immediately improved static balance in healthy individuals, patients with sensorimotor deficits, and individuals with FAI. These immediate enhancements occur while a person receives SRS during a balance task. Interestingly, SRS may be better for improving balance in individuals with sensorimotor dysfunction than those without impairments. A recent research report supports the effectiveness of SRS for enhancing balance in individuals with FAI who have sensorimotor deficits. Static single leg balance was improved by 8% when subjects with FAI who were administered SRS during a balance task. These immediate improvements may serve to permit individuals with FAI to perform balance activities during therapy that they might not be able to perform otherwise.

However, a dynamic balance test may be more useful than a static assessment for determining the effects of SRS on function. Dynamic balance is important to examine because individuals report symptoms of ankle instability while performing physical activity and dynamic stability is necessary for completing functional therapeutic exercises in rehabilitation. Single leg jump-landing tests have been used to assess the effects of FAI on dynamic balance. A common measure used to assess dynamic balance is time-to-stabilization (TTS), which has been reported as an accurate test for identifying anterior/posterior (A/P) and medial/lateral (M/L) postural stability deficits associated with FAI. In addition, TTS has been used to assess treatment effects of coordination training with and without SRS on single leg dynamic balance. Thus, TTS is an appropriate measure for assessing the immediate treatment effects of SRS on dynamic balance and it has potential for providing an indication of how individuals might perform functional balance activities in rehabilitation.

The usefulness of SRS for immediately improving dynamic single leg balance may enhance rehabilitation for FAI. While in theory this therapy may be clinically effective, no evidence has been published on the immediate effects of SRS on dynamic single leg balance in subjects with FAI. We believe that this significant gap in literature needs addressed to clarify potential benefits of SRS on dynamic single leg balance. Thus, the purpose of this study was to determine immediate benefits of SRS on A/P and M/L TTS in subjects with FAI. We hypothesized that A/P and M/L TTS would improve with SRS over a control condition.

2. Materials and methods

2.1. Subjects

Subjects read and signed a consent form approved by the Committee for the Protection of the Rights of Human Subjects prior to their participation in this study. Five males and seven females with unilateral FAI (69 ± 15 kg; 173 ± 10 cm; 21 ± 2 years) participated in this study. Seven subjects had FAI on their dominant leg (leg used to kick a ball), while the remaining five subjects had FAI on their non-dominant leg. The inclusion criteria for FAI were a minimum of one ankle sprain that required immobilization, report at least two “giving-way” sensations at the ankle within the past year, and participate in physical activity for more than 3 h per week. Subjects reported an average of 3 ± 1 ankle sprains and 5 ± 4 “giving-way” sensations within the 12 months prior to their participation in this study. Additionally, subjects had an average score of 31 ± 5 on the Ankle Joint Functional Assessment Tool (AJFAT) (values equal to or greater than 26 are indicative of FAI). Potential subjects were excluded if they sustained an ankle sprain within 6 weeks of inquiring about participating in this study. Additional exclusion criteria were a history of lower extremity injuries (other than sprains of the ankle) and impairments that affected balance (e.g., vestibular or visual impairments). Mechanical ankle joint instability was neither an inclusion or exclusion criteria.

2.2. Single leg jump-landing protocol

First, we assessed subjects maximum vertical jump height. The starting position for this maximum vertical jump test was 70 cm from a Vertec (Sports Imports, Columbus, OH, USA). The Vertec has adjustable plastic rods that can be set to specific heights to assess maximum jump height. Subjects were permitted to use a jump technique that allowed them to jump maximally; however, they were required to perform a two-footed takeoff and jump from a standing position. Subjects were not allowed to take steps prior to jumping. The maximum vertical jump height was assessed three times, and the highest jump was recorded as the subject’s maximum jump height.

The single leg jump-landing test was then performed. Plastic rods on the Vertec were set at 50%—55% of subjects’ maximum
jump heights. Subjects began this test standing 70 cm away from the Vertec, which was aligned with the center of a force plate (Vertec force plate model # 4060; Bertec Corp., Columbus, OH, USA). They were then instructed to use a jumping technique that allowed them to generate enough force to reach between 50% and 55% of their maximum jump height with their fingertips. Subjects were required to reach at least the 50% percent mark, but could not jump higher than 55% of their maximum jump height. They were allowed to swing their arms during the jump, but were required to hold their reaching arm at 180 degrees of shoulder flexion after taking off. This reaching arm was ipsilateral to the leg with FAI. After touching within the 50%—55% range, subjects landed on their leg with FAI atop the force plate, stabilized quickly, and remained as motionless as possible in a single leg stance for 20 s.

Single leg jump-landing tests were performed under SRS and control (no SRS) conditions. Stochastic resonance stimulator units (Afferent Corp., Providence, RI, USA) with surface electrodes (2 × 2 cm) self-adhesive gel pads (Model Platinum 896,230, Axelgaard Mfg. Co., Ltd., Fallbrook, CA, USA) were placed on the skin over the muscle bellies of the lateral soleus, peroneus longus, and tibialis anterior. Additionally, electrodes were placed on the anterior talofibular ligament and deltoid ligament. Stimulators delivered SRS via subsensory electrical noise (Gaussian white noise, zero mean, SD = 0.05 mA) to ankle muscles and ligaments. The noise amplitude of 0.05 mA has been used in previous SRS studies to improve balance.

Three practice trials were performed prior to data collection. Then, subjects performed three trials for each treatment condition. A randomized block design was used to determine test order for SRS and control conditions. Subjects were blinded to treatment conditions because SRS was subsensory. During SRS trials, the device was turned on and subjects were then instructed to jump immediately. The SRS was then shut off after subjects stepped off of the force plate. Lastly, subjects were retested if they failed to jump within the 50%—55% range, hopped on their test leg after landing, or touched the ground with their non-weight bearing leg after landing.

2.3. Data collection and reduction

Ground reaction force data were collected from the force plate at a sampling rate of 180 Hz. Signals were then passed through a BNC adapter chassis that was interfaced with an analog-to-digital board within a personal computer. These signals were then converted to ground reaction force vectors and moments. Data were filtered using a second order recursive low-pass Butterworth digital filter with an estimated optimum cutoff frequency of 12.53 Hz.

A customized LabVIEW (National Instruments Corp., Austin, TX, USA) software program computed A/P and M/L TTS. A/P and M/L components of the ground reaction force data were analyzed separately for each subject, but the same procedure was used for both components. First, the last 10 s of the ground reaction forces were analyzed to find the smallest absolute ground reaction force range for each component. These ranges were accepted as the optimal range of variation values. A/P and M/L components of the ground reaction force data were then rectified. An unbounded third order polynomial was fit from the peak force to the last data point for each component. TTS for each component was the point where the unbounded third order polynomial was equal to or less than the respective optimal range of variation value.

2.4. Statistical analysis

Average A/P and M/L TTS values for each treatment condition were computed in PASW version 18.0 (SPSS, Inc., Chicago, IL, USA). Alpha level was set a priori at $p \leq 0.05$ to indicate statistical significance. One-tailed paired samples $t$ tests compared SRS to control conditions for A/P and M/L TTS. Effect size $d$ values were calculated for each $t$ test. Average percent improvements for each TTS measure were also computed for all subjects and average improvement of eight subjects who improved with SRS (subjects who did not improve were removed). No improvements were defined as increased TTS with SRS over a control condition. Lastly, to provide insight on why some subjects did not improve with SRS, we computed effect size $d$ values for comparing responders and non-responders on frequency of sprains, frequency of “giving-way”, and score on the AJFAT.

3. Results

SRS significantly improved A/P TTS over the control condition (SRS = 1.32 ± 0.31 s, Control = 1.74 ± 0.80 s; $t_{(11)} = -2.04$, $p = 0.03$; $d = 0.76$). The average percent improvement for A/P TTS with SRS was 24% ($n = 12$) and increased to 34% ($n = 8$; SRS = 1.32 ± 0.35 s, Control = 2.01 ± 0.86 s) when four subjects who did not improve were removed. SRS did not affect M/L TTS (SRS = 1.95 ± 0.40 s, Control = 1.92 ± 0.48 s; $t_{(11)} = -0.20$, $p = 0.42$; $d = -0.07$). The average percent improvement for M/L TTS with SRS was 2% ($n = 12$) and increased to 15% ($n = 8$; SRS = 1.75 ± 0.30 s, Control = 2.06 ± 0.50 s) when four subjects who did not improve were removed.

Using effect size $d$ values to detect mean differences, non-responders had greater mean values than responders on frequency of sprains, frequency of “giving-way”, and score on the AJFAT. Small effect size $d$ values were found for comparing non-responders and responders for frequency of sprains (non-responders = 3.00 ± 1.12, responders = 2.71 ± 0.94; $d = 0.28$) and frequency of “giving-way” (non-responders = 5.50 ± 4.70, responders = 4.15 ± 3.76; $d = 0.32$). A high effect size $d$ value was found for comparing non-responders and responders on the AJFAT (non-responders = 33.38 ± 4.34, responders = 29.79 ± 4.35; $d = 0.83$).

4. Discussion

The most important finding of this study was that SRS delivered to the lower leg muscles and ankle ligaments...
improved dynamic single leg balance by reducing A/P TTS in subjects with FAI. These findings support the use of subsensory noise as an effective therapy for improving sagittal plane dynamic single leg balance. We did not identify specific neural mechanisms for improving balance with SRS in this study, but we suspect based on the stochastic resonance literature that this complimentary therapy facilitated afferent signal detection and efferent output.12,13

Increasing dynamic stability with SRS may have implications on reducing recurrent sprains and allowing individuals with FAI to perform balance exercises in rehabilitation that they may not be able to perform successfully without the use of SRS. Our current results indicate that A/P dynamic balance was improved by 24%. Previous research has indicated that A/P TTS deficits associated with FAI range between 22% and 40% when comparing FAI to stable ankles.11,19–21 Our results of this current study indicate that SRS returns A/P TTS to within normal limits of stable ankles. Previous research has also demonstrated that SRS was effective in improving static single balance in subjects with FAI by 8% over a control condition.9 Thus, clinicians may use this complimentary therapy to facilitate static single leg balance and sagittal plane dynamic single leg balance. This therapy may be critical for individuals with FAI who cannot balance on a single leg or perform single leg hop exercises effectively during rehabilitation. SRS may allow these individuals to perform dynamic single leg balance exercises earlier in therapy, which may facilitate and enhance rehabilitation. Clinically, this SRS treatment effect may translate to reducing recurrent ankle sprains. Researchers have indicated that balance training decreases ankle sprain injury and improvements in balance between 4% and 9% have been associated with a reduction in sprains.23 Our immediate effect exceeds these improvements, which is one reason we conjecture that this therapy may have implications for decreasing ankle sprains. This theory is purely speculative because we did not study the effects of SRS on recurrent ankle sprains. Future research should explore the clinical effectiveness of SRS on reducing recurrent ankle sprains in subjects with FAI.

Afferent signal detection is critical for initiating postural reflexive muscle contractions that enhance balance and SRS may facilitate balance improvements because of its ability to increase sensory feedback. Several neural mechanisms exist for SRS to enhance the ability of mechanoreceptors to detect sensory signals. Electrical subsensory noise transmitted transcutaneously can add constructively to subthreshold signals to create suprathreshold ones that can be detected by mechanoreceptors.14 In addition, this subsensory noise can stimulate mechanoreceptors to bring membrane potentials closer to threshold by changing ion permeability.13 Thus, mechanoreceptors are primed to fire in the presence of real sensory signals, especially subsensory signals that would typically go undetected.15 SRS can also contribute to preceding influential activity that converges on gamma motor neurons.13 Neurologically, input arising from mechanoreceptors (e.g., cutaneous, muscle spindle, Golgi tendon organs, articular) increase gamma motor neuron activation. SRS that influences gamma motor neurons can, in turn, activate muscle spindles.13 Through these direct and indirect pathways, SRS sensitizes muscle spindles to detect sensory signals that are important for maintaining balance and dynamic joint stability.

A link between sensorimotor deficits associated with FAI and poor single leg balance has been established, and theoretical framework is developing to explain how individuals with ankle instability cope with impairments to maintain balance.5,24 Recently, McKeon et al.24 have used the dynamic systems perspective to explain why ankle instability may cause a re-weighting of the sensory system to provide feedback relevant for maintaining balance. Sensory impairments reduce the degrees of freedom (defined as the interaction between the task, organism, and environment) along the lower extremity kinetic chain to decrease the variability in movement execution, making kinetics more predictable.24 In the case of ankle instability, movement variability may be decreased because sensory deficits from the organism reduces the degrees of freedom. As a result, the sensorimotor system re-weights sensory input to available functioning mechanoreceptors to allow successful completion of a movement.24 During single leg balance, McKeon et al.24 speculated that plantar cutaneous receptors and mechanoreceptors in the triceps surae input are re-weighted to provide sensory feedback necessary to make sagittal plane movement less variable and, therefore, more predictable for maintaining stability when mechanoreceptors in ankle ligaments are unavailable.24 Although re-weighting sensory input facilitates balance to some degree, sagittal plane instabilities will still be present because maximal input from damaged mechanoreceptors is not available.24 Based on the aforementioned information, we speculate that the SRS may have facilitated this re-weighting process to improve dynamic single leg balance. However, SRS could also have allowed ineffective mechanoreceptors to reach threshold and transmit sensory information vital for enhancing sagittal plane stability.

We may not have maximized our treatment effects because we did not optimize the noise intensity. Researchers indicate that enhancements with SRS can be optimized at a specific input intensity.9,13 Essentially, improvements with SRS will increase to a maximum intensity and decrease thereafter; often worsening compared to a control condition as the intensity approaches threshold.13 This phenomenon is often described as stochastic resonance behavior, which can be presented as an inverted “U” shape when plotting percent improvement over a control condition. A limitation to this study is our use of a single subsensory intensity for all subjects, which could have limited the treatment effect when small percentage improvements for some subjects were combined with high percentage improvements of others. For example, A/P TTS percent improvements with SRS increased 10% when four subjects who did not improve with SRS were removed from analysis. We want to note that this increase was due mainly to the control average A/P TTS value increasing. Furthermore, we did not find improvements in frontal plane dynamic single leg balance. However, M/L TTS percent improvements with SRS increased by 13% when four subjects who were impaired with SRS were removed from analysis. This increase percentage was due to the SRS M/L TTS value decreasing. Perhaps using
an optimized intensity would have produced immediate SRS effects in all subjects. Although the stimulation intensity was not optimized, we want to mention that using the same sub-sensory intensity for all subjects is the most widely accepted protocol in the SRS literature.

Our analysis comparing responders and non-responders indicates that the degree of ankle instability may be a contributing factor to responding (or not responding) to SRS. In other words, subjects with greater instability did not improve with SRS. We operationally defined degree of ankle instability by examining the frequency of sprains, frequency of “giving-way”, and score on the AJFAT. Those with more sprains and “giving-way” may have a greater degree of instability and subjects with greater scores on the AJFAT have a decreased ability to perform functional activities because of the presence of FAI. Our sample size was small and we elected to use effect size values over \( t \) tests to examine potential differences in response. Our \( d \) values ranged between 0.28 and 0.83, indicating that non-responders had greater means than responders and mean differences between groups should be statistically detectable given adequate power. Future research may explore how these ankle instability factors affect response to SRS.

5. Conclusion

We found that SRS is effective for improving sagittal plane dynamic single leg balance in subjects with FAI. However, this therapy did not improve frontal plane dynamic balance. Clinicians might use this complimentary therapeutic device to facilitate balance improvements with sagittal plane dynamic single leg balance exercises that patients may not be able to perform otherwise. Future research can explore the effects of an optimal SRS intensity on improving dynamic single leg balance in subjects with FAI.

References