Gait & Posture 63 (2018) 27–32

Contents lists available at ScienceDirect

Gait & Posture

journal homepage: www.elsevier.com/locate/gaitpost

Full length article

Effect of noise stimulation below and above sensory threshold on postural sway during a mildly challenging balance task

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ARTICLE INFO

Keywords:
Balance
Noise stimulation
Electrical stimulation
Stochastic resonance

ABSTRACT

Background: Mechanical and electrical sub-sensory noise stimulation applied to the sensory receptors has been shown to improve performance during postural balance tasks. This improvement has been linked with the Stochastic Resonance (SR) phenomenon. It is not clear if noise levels above sensory threshold can also lead to a reduction in postural sway.
Research question: The aim of this study was to investigate the different effects of sub- and super-sensory electrical noise stimulation applied to the Tibialis Anterior muscle during several repetitions of a mildly challenging single-leg postural balance task.
Methods: Fifteen healthy individuals participated in this study. Participants performed 25 repetitions of a balance tasks where they leaned forward and maintained a pre-determined position for 20 s. Each participant experienced 5 different stimulation levels (no-stimulation, 70%, 90%, 110% and 130% of their sensory threshold ST) for 5 times in a randomized order. Optimal stimulation (OS) was defined as the stimulation intensity minimizing the standard deviation of postural sway in the anteroposterior direction.
Results: ~57% of the participants presented levels of OS below ST. We did not observe a clear SR-effect, characterized by a U-shaped relationship between the performance metric and the stimulation intensity. OS led to a selective improvement in all the anteroposterior posturographic parameters analyzed. Stimulation below ST led to an improvement in most of the balance features, while stimulation above ST led to an increase in postural sway.
Significance: Our results suggest that OS can be found both below and above ST although stimulation below ST appears to be more effective in reducing postural sway.

1. Introduction

Noise is an inherent characteristic of all signals in the sensorimotor system [1]. Several studies in the past two decades have shown that adding mechanical or electrical noise to the sensorimotor system during static and dynamic tasks can be beneficial to motor task performance [2–7]. An abundance of research has tested the effects of both mechanical and electrical noise stimulation during the performance of postural balance tasks. Mechanical noise stimulation applied to the plantar surface of the foot and to joints of the lower extremity has been shown to improve postural balance by decreasing sway in both healthy [8], elderly [9] and impaired individuals [10]. Similar effects have been observed using electrical noise stimulation applied to joints [11] and muscles [12,13] in healthy individuals and after orthopedic injuries [14–16]. The efficacy of noise stimulation in the sensorimotor system is reportedly related to the stochastic resonance (SR) phenomenon [17]. SR is characterized by an improvement in the reception of weak stimuli in non-linear systems in the presence of a particular optimal level of additive noise [18–23].

Most of the previously published studies on noise stimulation during postural balance tasks have tested only a few levels of noise below the sensory threshold (ST). Testing noise intensities that a person cannot feel, in fact, rules out confounding factors affecting motor task performance related to the increase in attention that localized tactile sensations may cause. On the other hand, noise stimulation has several times been proposed as a possible aid during physical therapy for persons affected by a peripheral sensorimotor deficit [10,15,16,24]. In this perspective it is irrelevant whether an increase in sensorimotor acuity and a relative increase in performance is due to a SR effect or co-caused by improved perceptual attention [24].

In this work we performed an experiment with the purpose of clarifying the effect of different levels of electrical noise stimulation,

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https://doi.org/10.1016/j.gaitpost.2018.04.031
Received 30 November 2017; Received in revised form 27 March 2018; Accepted 21 April 2018
0966-6362/

above and below ST, on postural balance during a mildly challenging task performed by healthy individuals. The task consisted in a one-legged stance exercise where participants were asked to lean forward and maintain a fixed position. Performance in this task critically depends from proprioceptive information coming from the spindles of the tibialis anterior (TA), that we targeted using electrical noise stimulation. We analyzed if a SR-like behavior, characterized as a U-shaped curve mapping performance to noise intensity [18], is observable when testing different levels of stimulation. We also investigated the different effects of electrical noise stimulation intensities below and above ST with the aim of assessing if there are clear differences between stimulation intensities that individuals can and cannot feel.

2. Methods

2.1. Participants

Fifteen healthy individuals (6 females, age = 23.2 ± 0.7 years) participated in this study. Inclusion criteria consisted of the absence of impairments that would affect the performance of the experimental motor task. All individuals agreed to participate in the study by signing an informed consent form. All procedures were conducted in accordance with the policies of the Human Research Ethics Committee of UCD and with the Declaration of Helsinki.

2.2. Experimental procedures

Participants were asked to perform a set of mildly challenging single-leg postural balance tasks whilst being exposed to different intensities of stimulation applied to the TA muscle of their stance leg. Participants performed the single-leg postural balance motor task barefoot on a force-plate (AMTI, Watertown, MA). All testing was performed on the participants' dominant leg, defined as the leg they would use to kick a ball. During each repetition of the motor task the participants were asked to lean forward until the antero-posterior (AP) component of their center of pressure (CoP) deviated by 20% of their height from the resting position during single-leg stance (see Fig. 1A–B). Participants were not given visual feedback of their CoP but were told when to stop increasing their forward leaning by an operator monitoring the CoP trajectory in real time. Once the target CoP AP position was reached participants were asked to hold the position as still as possible while fixating their gaze on a marker positioned at eye-level in front of them and while keeping their arms tight by their sides for 20 s. The CoP trajectory of the participants was recorded during these 20 s. The length of the trial is less than the suggested length of 30 s [25], but was selected to minimize the length of the experiment given the high number of task repetitions that the subjects performed.

Participants were asked to maintain a small amount of flexion at the stance knee joint during the task and were asked to raise the foot of the non-stance leg such that the knee flexion angle approached 90°. At the beginning of the testing session, participants performed three practice trials to familiarize themselves with the required body positioning.

After the practice trials a procedure for the determination of the participant's ST was undertaken. Two surface electrodes (5 × 5 cm Axelgaard ValuTrode Lite) were placed on prepared areas of the skin over the TA (at about 2/3 of the muscle length in both directions) on each participant's dominant leg. The TA was chosen due to its role in the control of the AP direction of the CoP and given its importance as a source of proprioceptive information in this motor task [26].

Low-level electrical white Gaussian noise current stimulation was applied through an electrically isolated stimulator (2200 AS.I., A-M Systems, WA) driven by a voltage noise signal supplied by a laptop equipped with custom software. To determine the ST, a noise current stimulation with a standard deviation of 100 μA and a bandwidth of 0.1–1000 Hz was supplied for 15 s and the subject was asked if she/he could feel the stimulation. If the subject could not feel the stimulation the procedure was repeated and the current intensity was increased by 10 μA. The ST was defined as the first stimulation level that the subject was able to feel.

After the determination of the ST the participant was asked to perform 25 repetitions of the single-leg stance postural balance task. The test protocol consisted of 5 repetitions of 5 different levels of stimulation (no stimulation (NS), 70%, 90%, 110% and 130% of the ST) performed in a randomized order. In order to avoid possible fatigue effects, subjects rested for 2 min after 5 task repetitions. Trials during which participants were not able to maintain the required single-leg postural balance position were repeated at the end of the data collection.

2.3. Data analysis

Different features (or "sway parameters") extracted from the CoP were analyzed during the 25 repetitions of the postural balance motor task, specifically: AP and mediolateral (ML) standard deviation (SD), range and path length, total path length and the area of the ellipse containing the data. All parameters were normalized with respect to the participant's height and were expressed as a percentage of it. For each of the different stimulation intensities, the median value (preferred to the mean to limit possible effects of outlier trials, given the task difficulty) of each parameter across the 5 repetitions was used to represent each participant's feature value for that stimulation intensity.

Since the task consisted in maintaining a steady position after a displacement in the AP direction, we defined the optimal stimulation (OS) value for each participant as the intensity for which they showed

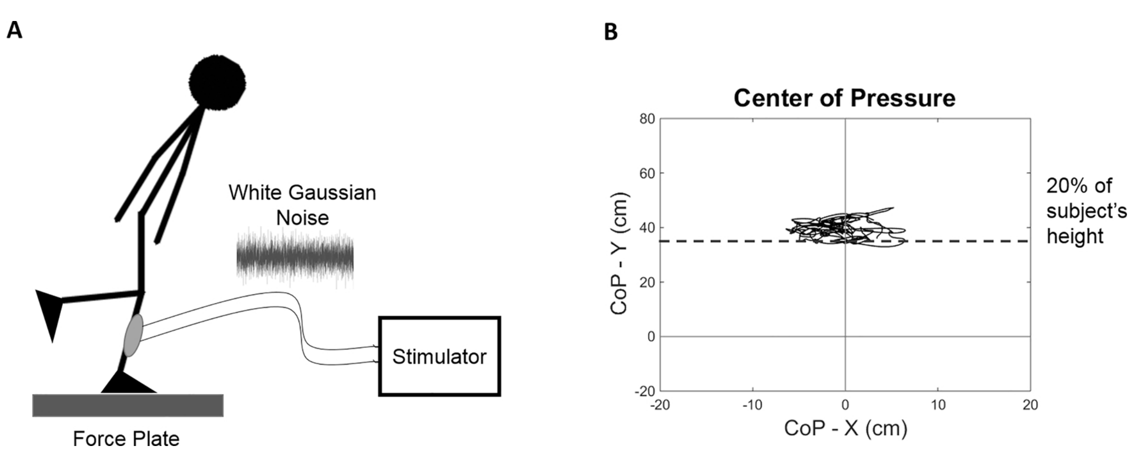

Fig. 1. The Experimental Setup. (A) Subjects were asked to lean forward until the position of their CoP reached 20% of their height in the forward direction. Stimulation, consisting of White Gaussian Noise was directly applied at the TA muscle. **(B)** An example of stabilogram of one of the subjects during one of the tasks.