



Full length article

The effect of augmented somatosensory feedback on standing postural sway

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ABSTRACT

Impaired balance resulting from reduced postural control occurs with aging and various medical conditions. Sensory input for balance control is provided by the visual, vestibular and somatosensory systems. Previous research suggests that increased proprioceptive feedback from various lower extremity devices improves balance. Mixed results have been reported with the use of orthoses such as ankle foot orthoses (AFOs). In this study, 20 healthy subjects wore footplates in their shoes or straps around their lower legs in order to imitate the somatosensory feedback produced by wearing AFOs, but without providing ankle restriction. Subjects' standing balance was assessed using force plates and computerized dynamic posturography (the sensory organization test-SOT) to determine if either the footplates or the lower-leg straps would affect standing balance. The results revealed no significant difference with the use of the footplates, however, wearing the straps resulted in reduced postural sway for conditions when visual cue deprivation was combined with manipulation of somatosensory or vestibular feedback. This effect was more pronounced in participants with the poorest baseline measures of balance. These findings suggest that lower extremity devices, such as AFOs, may augment somatosensory feedback that could improve balance during challenging sensory deprivation conditions, independent of orthotic support at the ankle.

1. Introduction

The human body tends to sway when standing due to a high center of mass and a relatively small base of support [1,2]. Postural sway measures reflect the coordination of musculoskeletal movements regulated by sensory feedback to maintain standing balance [3–5]. Sensory or muscular deficiency resulting in reduced postural control is a common occurrence with aging [6,7] and a variety of medical conditions [4,8]. Balance impairments pose a risk of injury resulting from falls, impede optimal function, cause compensatory behavioral responses and reduce quality of life [7].

The visual, vestibular and somatosensory systems provide information about spatial positioning, acceleration and mechanical forces acting on the body during standing balance. (In this manuscript, the term 'somatosensory' is intended to include both cutaneous sensation and proprioception). The multiple redundancies of these feedback systems allow alternate sources of sensation to be used as a substitute for missing sensory information [9]. For example, allowing a subject to lightly touch a fingertip to a stationary object has been shown to increase somatosensory feedback and aid balance when the vestibular or visual systems are impaired [10]. Devices worn externally on the body

cause stimulation to mechanoreceptors, which may enhance somatosensory awareness, facilitating feedback for correction of directional change, allowing for smaller counter movements and resulting in improved balance [3,5,8]. This effect has been reported with the use of interventions such as cutaneous stimulation or compression applied to the leg [11–13]. Similar effects have been reported with use of stimuli to the foot and ankle, such as wearing high-top shoes or various types of textured or contoured insoles [8].

Although some types of external devices seem to improve balance, the effect of lower extremity bracing, such as ankle foot orthoses (AFOs), on postural sway is less clear. Multiple studies and reviews have been conducted to determine the effects of various types of AFOs on standing balance [14–16]. Some researchers have found that wearing AFOs reduced postural sway suggesting that the device provides augmented somatosensory feedback [17–19]. Others have found AFOs to be detrimental to balance, theorizing that this effect may be due to reduction of natural ankle movement as a result of the AFO [20,21]. This discrepancy in the existing literature may be due to the large variety of AFO styles studied, the diverse subject populations, and non-standardized measurement protocols. A recent systematic review [22] suggested that AFOs may be beneficial to standing balance if the

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orthoses do not restrict ankle motion.

The present study investigated the effect of augmented somatosensory feedback on standing balance from two of the most common components of an AFO: the strap and the footplate. Typically, these components are joined by the structure of the orthosis, but in this instance they were used separately in order to avoid the confounding effects of a device which would limit ankle range of motion. Center of pressure (COP) excursions while standing quietly on a force plate were measured; and, sensory organization test (SOT) equilibrium scores were determined from a computerized dynamic posturography (CDP) assessment. It was hypothesized that augmented somatosensory feedback from the AFO straps or the textured footplates would reduce COP excursions during static and dynamic stance.

2. Methods

Twenty college age subjects (12 females, 8 males, mean age: 21.8 yrs; height: 171 cm; mass: 72.81 kg) participated in the study. All participants gave informed consent after reviewing an institution-approved human subjects' consent document. Subjects were fitted for the AFO straps and the footplates. The AFO straps were fabricated from 38 mm wide padded Velcro strapping consistent with the type used most frequently to secure orthoses. The straps were placed 4 cm below the Fibular head, which is the recommend proximal trimline location for many styles of AFO. The textured footplates were constructed out of Optex acrylic with a 0.15 mm raised grid pattern texture over the surface of the material. The footplates were inserted into the subject's shoes on top of the standard footbed. The straps and footplates were applied to all subjects by the same certified Pedorthist while the subject was seated in a chair adjacent to the testing location. The AFO straps and footplates were applied before each trial and removed immediately after each trial. All testing took place with subjects wearing their own athletic footwear and standardized ankle-height athletic socks.

Standing postural sway was evaluated using a force plate (Kistler Instrument, Corp.) and via the SOT (Neurocom Equitest CDP). These two measurement systems were selected because both are commonly used to assess postural sway [23–26]. All force plate testing was completed first. Subjects were instructed to stand quietly for 60 s on a force plate with hands relaxed at the side of the body, feet parallel and together. This same stance configuration was used for all testing conditions.

Three variations of eyes open (EO) conditions were tested on the force plate: a standing baseline trial without straps or footplates (Baseline), wearing the textured footplates (Footplates) inside bilateral shoes, and wearing straps on bilateral lower legs (Straps). For the EO trials the subjects stood staring at a fixed picture located approximately 1 m anterior to the force plate. Data were also collected for three variations of eyes closed, head tilted back (ECHB) conditions: standing in the ECHB position without straps or footplates (Baseline), wearing the textured plates in bilateral shoes (Footplates), and wearing straps on bilateral lower legs (Straps). Each subject's posture was standardized for the ECHB conditions with the use of a stationary visual target placed approximately 15 cm above each subject's head. At the beginning of each ECHB trial, subjects were instructed to tip their head back until the target was directly above their eye line and then close their eyes and maintain that position. The ECHB position was chosen to eliminate visual input and reduce vestibular input in order to isolate the somatosensory control of balance [3,5,9,27]. The order of all force plate testing conditions was randomized and subjects were seated for a 60 s rest period between each test. Force plate data were recorded and analog-to-digital converted at 50 Hz. Anterior-posterior (AP) and medial-lateral (ML) COP range were determined for the first 20 s epoch of each sample (BioWare, Version 5.2.2.4) to match the time sample epoch of the CDP tests.

CDP testing commenced immediately following force plate testing. The Neurocom Smart Equitest CDP® system has a movable dual force

plate platform and a movable visual surround. Subjects wore a safety harness during testing to prevent falls. The SOT consisted of one trial of each of six 20 s subtests in which subjects stood as still as possible during various balance tasks. The six subtests of the SOT were designed to challenge the sensory systems, with escalating levels of difficulty from standing still on a fixed surface with eyes open (subtest 1), to standing on a sway referenced surface with sway referenced visual surround (subtest 6) [28].

Each subject completed one practice SOT in order to become familiarized with the testing procedure and to reduce the learning effect [29]. Following the practice test, subjects completed SOTs in randomized order with the Baseline, Straps and textured Footplates conditions. The equilibrium score was recorded for each subtest within the SOT (Neurocom Equitest CDP). Subjects were seated for an approximately one-minute rest period between each SOT.

The force plate and CDP data were analyzed using SPSS statistical software (SPSS Inc., Chicago, IL). Each of the dependent measures were checked for sphericity and then compared across Baseline, Straps and Footplates conditions using repeated measures ANOVA. Post-hoc pairwise comparisons with Bonferroni correction were used for any significant results. The relationships between SOT scores in Baseline, Footplate and Straps conditions were analyzed via linear regression. Significance was defined as $p < .05$.

3. Results

The performances of male and female subjects were compared for 30 conditions (12 force plate conditions: EO and ECHB baseline, footplate, straps; 18 SOT subtests: Conditions 1 through 6: baseline, footplate, straps) using independent T-tests. The female subjects had lower mean equilibrium scores than the males in the baseline condition of SOT 1 (Females 94.5, Males 95.5. $p = 0.025$). No other significant differences were found; the results reported herein are collapsed across sex. There were no significant changes from the baseline postural sway range in AP or ML directions in the EO conditions with either the footplates or straps (Table 1). The ECHB conditions also showed no significant difference from baseline in AP COP sway range with the footplates or straps. A significant reduction of ML postural sway compared to baseline ($p = .011$) was observed in ECHB condition with the use of the straps, but not with the use of the footplates.

There were no significant differences in equilibrium scores for the first 5 subtests of the SOT (Fig. 1). In subtest 6, there were significant improvements in the equilibrium scores when wearing the straps when compared to the baseline score ($p = .012$), and when compared to the equilibrium score when wearing the footplates ($p = .024$). Fig. 2 shows individual equilibrium scores for SOT subtest 6. Linear regression lines were fit to the two functions (the dotted line represents the fit to the straps data, the dashed line shows the fit to the footplate data, and the solid line shows a function with unity slope). A similar pattern of improvement over baseline can be seen for both conditions; however, there was less variation in the Straps condition scores than the Footplates condition scores, and the slope of the function is less for the footplate data (Footplates $y = 0.299x + 55.8$; $r^2 = 0.101$, Straps

Table 1
Center of pressure (COP) range on force plate.

	Eyes Open (EO)		Eyes Closed, Head Back (ECHB)	
	AP Range (cm)	ML Range (cm)	AP Range (cm)	ML Range (cm)
Baseline	2.3 ± 0.8	1.3 ± 0.4	3.3 ± 0.7	3.5 ± 0.9
Footplates	2.2 ± 0.7	1.4 ± 0.5	3.2 ± 0.7	2.9 ± 0.7
Straps	2.4 ± 0.7	1.5 ± 0.6	3.4 ± 0.8	2.8 ± 0.6*

Note: AP is in the anterior-posterior direction, ML medial-lateral. Mean ± standard deviation.

* Significant difference ($p < .05$) from ECHB baseline measure.

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