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Impaired plantar sensitivity among the obese is associated with increased postural sway

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HIGHLIGHTS

- Obese participants exhibited impaired plantar sensitivity.
- Obese participants exhibited greater postural sway during quiet standing.
- Plantar sensitivity was correlated with postural sway.
- Impaired plantar sensitivity may impair balance among obese individuals.

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ABSTRACT

Impaired foot plantar sensitivity has been hypothesized among individuals who are obese, and may contribute to their impaired balanced during quiet standing. The objective of this study was to investigate the effects of obesity on plantar sensitivity, and explore the relationship between plantar sensitivity and balance during quiet standing. Thirty-nine young adults from the university population participated in the study including 19 obese and 20 non-obese adults. Plantar sensitivity was measured as the force threshold at which an increasing force applied to the plantar surface of the foot was first perceived, and the force threshold at which a decreasing force was last perceived. Measurements were obtained while standing, and at two locations on the plantar surface of the dominant foot. Postural sway during quiet standing was then measured under three different sensory conditions. Results indicated less sensitive plantar sensitivity and increased postural sway among the obese, and statistically significant correlations between plantar sensitivity and postural sway that were characterized as weak to moderate in strength. As such, impaired plantar sensitivity among individuals who are obese may be a mechanism by which obesity degrades standing balance among these individuals.

1. Introduction

An estimated 500 million people worldwide were obese in 2008, and the prevalence of obesity has nearly doubled since 1980 [1]. One of the concerns with the high prevalence of obesity is its association with an increased risk of falls. Each year, obese adults fall almost twice as frequently (27%) as their non-obese counterparts (15%) [2]. This is problematic because falls can be injurious [3]. The biomechanical and/or physiological mechanisms leading to the higher rate of falls among the obese are unclear. Understanding these mechanisms could lead to more effective fall prevention programs.

One mechanism by which obesity could contribute to falls is by degrading balance due to impaired plantar sensitivity on the bottom of the feet. Human standing balance control relies on feedback from the proprioceptive system [4]. This system includes cutaneous mechanoreceptors which detect pressure and deformation in the skin [5]. Studies have demonstrated that impairments in plantar sensitivity influence balance control among older adults and individuals with chronicle ankle instability [6–8]. Obesity increases postural sway during quiet standing [9], and may do so, at least in part, due to impaired plantar sensitivity. Higher plantar pressures have been reported among individuals who are obese [10], but no studies to our knowledge have investigated the effect of obesity on plantar sensitivity, or the association between plantar sensitivity and balance as a mechanism by which individuals who are obese exhibit impaired balance.

The objective of this study was to investigate the effect of obesity on plantar sensitivity, and explore the relationship between plantar

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sensitivity and postural sway. Our first hypothesis was that obesity would adversely affect plantar sensitivity. Our second hypothesis was that plantar sensitivity would be associated with postural sway. The results from this study will provide insight to the mechanisms by which obesity impairs balance, and potentially guide future efforts aimed at developing interventions to mitigate the delirious effects of obesity on balance.

2. Materials and methods

Thirty-nine young (age = 21.3 ± 2.6 years) adults recruited from the university population participated in the study. Participants included 19 obese (body mass index or BMI = 33.0 ± 2.9 kg/m^2; 14 females and 5 males) and 20 non-obese (BMI = 22.2 ± 2.2 kg/m^2; 14 females and 6 males) adults. Body fat percentage was also measured using skinfold caliper measurements at the front of the upper arm, back of the upper arm, below the scapula, and on the abdomen (1 cm to the right of the navel). Obese participants were required to have a body fat percentage above 35% for women and above 25% for men from these caliper measurements [11], as well as a BMI above 30 kg/m^2. All participants were free from any self-reported foot pain or known neurological conditions that might affect their performance in this test.

Participants completed one experimental session during which multiple measurements of plantar sensitivity were obtained while standing. Plantar sensitivity was operationalized as the force threshold at which an increasing force applied to the plantar surface was first perceived, and the force threshold at which a decreasing force was last perceived. Measurements were obtained immediately upon standing, and at two locations on the plantar surface of the dominant foot including the calcaneus and the head of the third metatarsal. Postural sway was then evaluated under three different conditions. Participants wore a T-shirt, tight-fitting pants, no shoes, and no socks during testing. Room temperature was controlled at 74 °F.

The setup and methodology was based upon a recent study investigating the effects of added weight on plantar sensitivity while upright standing [12]. Plantar sensitivity was assessed using a custom-designed platform (Fig. 1) and a digital force gauge (Extech, model 475,040, Nashua, NH, USA. The aluminum platform (40 × 81 cm) was covered in vinyl floor tile and included a 1.5 mm diameter hole so that a small stainless steel probe tip (diameter = 1 mm) attached to the force gauge could pass through and come into contact with participants' foot sole while standing. The position of the probe tip was controlled from beneath the platform via a manual lab jack (LJ750, Thorlabs Inc, Newton, New Jersey, USA) (Fig. 1).

Two practice trials were performed on each participant at the beginning of the experiment. Practice trials were performed at a random site on the plantar surface of the foot not including the two testing sites. Participants were then asked to sit for 10 min. To start testing, participants were asked to stand on the platform while the investigator positioned their foot so that the testing site was aligned with the hole in the platform. Participants were instructed to stand as still as possible, look straight forward, hold onto the bars in front of them to help standstill, and give verbal indication when they were able to feel the force by saying "Now". At the start of each trial, the probe tip was initially below the surface of the platform and not in contact with the plantar surface of the foot. After a random delay of up to 10 s, the investigator began manually rotating a dial on the lab jack (Fig. 1) in increments of approximately 60° every half second until given a verbal indication by the participant. Once the probe tip translated upward far enough to contact the plantar surface of the foot, this rotating pattern increased the force applied to the foot in a step-wise manner at a rate of—5 g every half second.

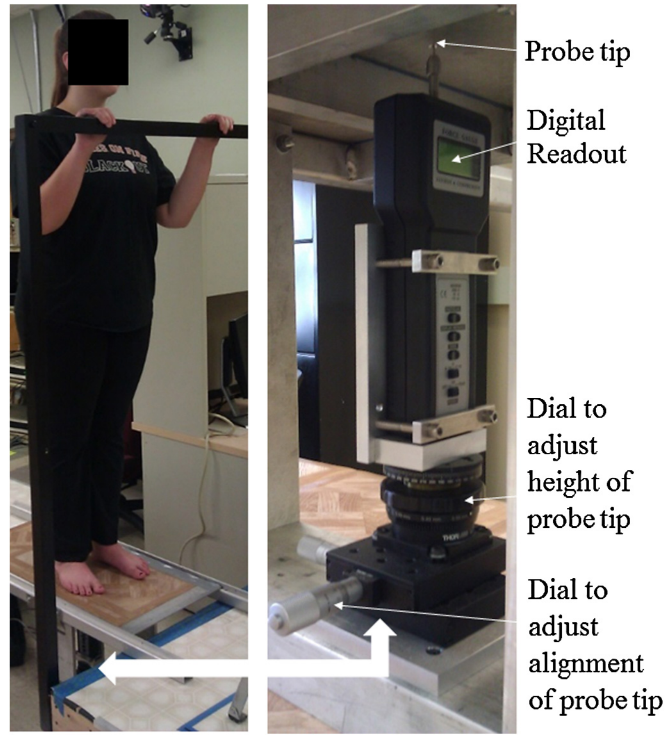

Fig. 1. Custom-designed platform to assess plantar sensitivity while standing (Digital force gage setup was mounted on lab jack under the platform. The investigators adjusted the vertical position of the probe by manipulating the lab jack, and read off the force threshold from the digital readout when indicated by the participants.).

After the participant detected the force, this force threshold was recorded, and the investigator continued to raise the probe tip until the force reached 180 g (a value well above all participants' force threshold). The lab jack was then used to translate the force probe tip downward, resulting in the force applied to the foot decreasing in a step-wise manner at a rate of—5 g every half second. Participants were instructed to give verbal indication when they were no longer able to feel the force by saying "Now". A total of four trials were performed at each site, with each trial involving the force increasing and decreasing one time. The order of the two sites was counterbalanced within each group. The experimenter also randomly picked one of the four increasing trials to check whether the participant was giving false verbal indication on their foot sensitivity, or experiencing phantom sensation, by delaying the initiation of the trial for 30 s after indicating the start of the trial. None of the participants gave indication before the start of the trial during the experiment.

Postural sway was then evaluated while participants attempted to stand as still as possible with bare feet, arms at sides and feet pointed forward and 7.5 cm apart. The trials were collected under three different sensory conditions: eyes-open (baseline), eyes-closed (impaired visual feedback), and eyes-closed with the head tilted backward (impaired visual, vestibular, and proprioceptive feedback). Tilting the head backward is thought to render balance-related vestibular information unreliable by placing the otolith organs outside their normal working range [13]. These conditions were imposed because impairing the visual and vestibular systems would make the balance control system more dependent upon the proprioceptive system (e.g. plantar sensitivity), and may strengthen the relationship between plantar sensitivity and balance. Participants were required to tilt their head backwards at least 30°, as measured by investigator observation. Three trials of 75 s were collected under each condition, and two minutes of rest