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Original Article

The effects of shoe heel height and gait velocity on position sense of the knee joint and balance

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Abstract. [Purpose] The aim of this study was to examine the effects of increased heel height and gait velocity on balance control and knee joint position sense. [Subjects and Methods] Forty healthy adults were randomly allocated to 4 groups: low-heel, low-speed group (3 cm, 2 km/h), low-heel, high-speed group (3 cm, 4 km/h), high-heel, low-speed group (9 cm, 2 km/h), high-heel, and high-speed group (9 cm, 4 km/h), with 10 subjects per group. Static and dynamic balance was evaluated using the I-Balance system and knee joint position sense using a goniometer. Measurements were compared using a pre- and posttest design. [Results] Increasing heel height and gait velocity decreased knee joint position sense and significantly increased the amplitude of body sway under conditions of static and dynamic balance, with highest sway amplitude induced by the high-heel, high-speed condition. [Conclusion] Increased walking speed in high heels produced significant negative effects on knee joint sense and balance control.

Key words: Shoe heel height, Static and dynamic balance, Knee joint position sense

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INTRODUCTION

Females commonly wear high heels to give an appearance of being taller and to accentuate the appearance of their legs[1)]. In addition, as they have social and cultural meaning, as well as psychosexual significance, high heels have become a consistent component of fashion trends for females[2)]. In fact, it has been reported that fashion-conscious young females can wear high-heel shoes for up to 8 hours per day while performing activities of daily living, such as standing and walking[3)]. Prolonged wearing of high heels may be a predisposing risk factor for impairments in body alignment, lower limb proprioception, and musculoskeletal injury[4, 5)]. It has been suggested that an interaction between high heels and hormonal factors could explain the 2-fold higher incidence of knee osteoarthritis in females, compared to males[6)]. Moreover, as they increase the magnitude of torque about the knee during standing and walking, high heels could increase the risk for knee joint injury and degenerative changes due to accumulated fatigue[7)]. Such degenerative changes could alter knee joint position sense, negatively affecting balance control and leading to lowered capacity for activities of daily living and mobility[8, 9)].

Balance control largely refers to the ability to maintain alignment of the body along the line of gravity and lower the amplitude and velocity of sway of the body center of gravity[10, 11)], and is strongly influenced by knee joint position sense. High heels narrow the base of support and restrict the area within which body sway must be controlled to avoid triggering a fall. Compounding this problem of balance control is the negative effect of high heels on knee joint position sense, which reduces the efficiency of the system to use proprioceptive information to strictly control body sway within the available base

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of support[5]. The chronic demand on lower limb muscles and soft tissues to manage these changes in proprioception and base of support can eventually lead to inefficient contraction of leg muscles and abnormal muscle lengths[12]. However, the effects of high heels on muscle activity, proprioception, and lower limb alignment have only been evaluated within the context of standing[4, 13], without consideration of the potentiating effects of walking in high heels. Therefore, the aim of our study was to examine the effects of increased heel height and gait velocity on balance control and knee joint position sense.

SUBJECTS AND METHODS

The study group comprised 40 healthy adults. All participants were right-foot dominant, naive to high-heel use, and had no previous history of neuromuscular disease, fractures, spine-related diseases, or lower limb surgery. None had prior experience with the study protocol. After being provided with a full explanation of the study procedure, without disclosure of the study purpose, participants gave informed consent. This study was approved by the Research and Ethics Committee at DongShin University.

Participants were randomly allocated to the low-heel, low-speed group (3 cm, 2 km/h, LL), the low-heel, high-speed group (3 cm, 4 km/h, LH), the high-heel, low-speed group (9 cm, 2 km/h, HL), or the high-heel, high-speed group (9 cm, 4 km/h, HH), with 10 subjects per group. The distribution of age, height, and weight within each group is reported in Table 1. Baseline measurements of static and dynamic balance and joint position sense were obtained prior to the experimental session. Participants in the LL and HL groups wore shoes with a 3-cm heel, while participants in the LH and HH groups wore shoes with a 9-cm heel. All walking trials were performed on a treadmill (T25, Motus, Korea), at 2 speeds for 20 min: 2 km/h for the low-speed group and 4 km/h for the high-speed group. Following the walking trial, participants removed their shoes and completed posttest assessments of static and dynamic balance, and knee joint position sense. All participants were evaluated under the same experimental conditions, and provided with an adaptation time of approximately 10 min before and after the measurements.

Static and dynamic balance tests were performed using an automatic balance calibration system (Model I Balance S, CyberMedic Co., Iksan, Korea). The I-Balance system provides a measure of the sway velocity of the center of gravity of the body and the total amplitude of sway, using a force platform equipped with 4 load cells. For static balance testing, participants stood on the force platform, with feet shoulder-width apart and hands folded across the chest. Participants were asked to look directly in front at a monitor providing feedback of the location of their center of gravity and to maintain the position within the spatial area provided by the program. Static balance was quantified by the length of time (s) the reference position of the center of gravity was maintained within the reference spatial area. For dynamic balance testing, participants assumed the same posture as for static balance testing but were asked to change the position of the center of gravity to match locations presented by the program: anterior, posterior, right, left, and along diagonals relative to their neutral position. Dynamic balance was quantified by the response time along each direction (s). Three trials of the static and dynamic tests were performed[14].

Knee joint position sense was evaluated using the DrGoniometer (CMD S.R.L., Milano, Italy) based on a smartphone application. Diagnostic tests using smartphone applications have recently been conducted for clinical and scientific diagnosis, and the reliability of the DrGoniometer application has been verified in previous studies[15, 16]. Participants were placed in the prone position, with eyes blindfolded and the torso and thighs stabilized using a belt. The knee being assessed was passively flexed to 90° and held for 5 s to provide participants with a sensory representation of the reference angle. Participants were then asked to actively flex their knee further to 120°, holding the new end-point position again for 5 s. The learning trial was repeated 3 times to ensure that participants had obtained an accurate sensory representation of 90° and 120° of knee flexion. For testing, the knee was again passively flexed to 90°, and participants were then asked to actively flex their knee further to 120°, telling the experimenter when they felt they had reached the target knee angle. A total of 6 measurements were completed and the difference between the target angle of 120° and the measured angle calculated. The mean error over the 6 trials was used in the analysis. The assessments were performed under identical experimental conditions for the pre- and post-test, and all tests were performed by the same experimenter. The tests were repeated after 48 h to measure learning effects[17].

All analyses were performed using SPSS 18.0. The normality of the distribution of variables was evaluated using the

Table 1. General characteristics of the study group (n=40)

	Group			
	LL (n=10)	LH (n=10)	HL (n=10)	HH (n=10)
Age (years)	21.6 ± 1.9	21.9 ± 2.2	22.0 ± 1.9	22.8 ± 2.0
Height (cm)	158.4 ± 5.5	157.2 ± 5.0	158.4 ± 8.0	158.5 ± 5.4
Weight (kg)	56.2 ± 5.0	57.6 ± 4.3	56.5 ± 4.2	57.4 ± 5.4

Values are expressed as the mean ± standard deviation.
LL(a): low-heel low-speed group; LH(b): low-heel high-speed group; HL(c): high-heel low-speed group; HH(d): high-heel high-speed group

Shapiro-Wilk test, with data transformation used as needed to achieve a normal distribution. Effects of heel height and walking speed were evaluated using a two-way analysis of variance (ANOVA), and statistical significance was set at an α-level of 0.05.

RESULTS

Changes in static balance as a function of shoe heel height and gait velocity are reported for each group in Table 2. Overall, we identified an increase in sway amplitude as a function of increased heel height and gait velocity, with an increase in sway amplitude of 0.05 in the LL group, 0.05 in the LH group, 0.11 in the HL group, and 0.19 in the HH group. A significant group ×time interaction was identified ($p<0.05$), with the condition of high heels and high velocity causing the largest increase in sway amplitude.

Changes in dynamic balance as a function of shoe heel height and gait velocity are reported for each group in Table 3. Sway amplitude increased by 0.54 in the LL group, 0.67 in the LH group, 1.26 in the HL group, and 2.29 in the HH group, again indicating that amplitude of sway increased as shoe heel height and gait velocity increased. A significant group × time interaction was identified ($p<0.001$), with the condition of high heels and high velocity causing the largest increase in sway amplitude.

Assessment of knee position sense provided evidence of an increased magnitude of error with increasing heel height and gait velocity. The magnitude of error in joint position sense across the 4 groups, using the reference position of 60°, was as follows: 0.68° for the LL group; 1° for the LH group; 0.86° for the HL group, and 4.62° for the HL group (Table 4). Again, a significant group × time interaction was identified ($p<0.05$), with the condition.

DISCUSSION

Shoes are essential to increase walking efficiency and for injury prevention[18]. An improper fitting of the shoe can negatively affect the body alignment and balance[19]. In particular, high-heel shoes can modify the position sense of the knee joint, which itself modifies the responsiveness of the muscles responsible for aligning the trunk and lower limbs along the line of gravity. These modifications in sensory-motor control can functionally reduce balance capacity and increase the risk for falls[20–22, 24].

Table 2. Changes of static balance according to shoe heel height and gait velocity (sec)

Group	Mean ± SD	
	Pre	Post
LL	0.34 ± 0.1	0.39 ± 0.1***
LH	0.36 ± 0.1	0.41 ± 0.1***
HL	0.34 ± 0.1	0.45 ± 0.2***
HH†	0.34 ± 0.1	0.53 ± 0.1***

*p<0.05, **p<0.01, ***p<0.001, Comparison between Pre and Post.
†p<0.05, ††p<0.01, †††p<0.001, Comparison between group.

Table 3. Change of dynamic balance according to shoe heel height and gait velocity (sec)

Group	Mean ± SD	
	Pre	Post
LL	1.69 ± 0.6	2.23 ± 0.9***
LH	1.66 ± 0.4	2.33 ± 0.8***
HL	1.50 ± 0.4	2.76 ± 0.9***
HH††	1.60 ± 0.4	3.89 ± 0.9***

*p<0.05, **p<0.01, ***p<0.001, Comparison between Pre and Post.
†p<0.05, ††p<0.01, †††p<0.001, Comparison between group.

Table 4. Change of position sense of knee joint according to shoe heel height and gait velocity (°)

Group	Mean ± SD	
	Pre	Post
LL	−0.64 ± 3.3	−1.32 ± 2.8
LH	−0.16 ± 5.7	−1.16 ± 2.2
HL	−0.76 ± 3.3	−1.62 ± 3.0
HH	−0.48 ± 3.0	−5.10 ± 4.2

*p<0.05, **p<0.01, ***p<0.001, Comparison between Pre and Post.
†p<0.05, ††p<0.01, †††p<0.001, Comparison between group.

Balance capacity has been shown to be closely correlated with proprioception, with knee joint position sense being an important component of proprioception influencing balance and walking performance[23]. Single-leg balance training on a trampoline has been shown to enhance knee joint position sense, resulting in increased balance capacity, measured by a significant reduction in the amplitude of body sway.

Our study contributes novel knowledge on the effects of wearing high heels on balance control. Specifically, we demonstrated that a trial of 20 min of treadmill walking with high heels was sufficient to lower the acuity of knee position sense and to increase the amplitude of body sway under both conditions of static and dynamic balance. Our findings are comparable to previous reports of the effect of high heels in increasing the amplitude and area of sway during static standing[4] and reduced dynamic stability during fore-aft walking[22]. Similar negative effects of high heels on sensory input were identified by a reduction in two-point discrimination and sensitivity to light tactile touch on the soles of the feet, and lower position sense of the great toe in young females who wore high heels for more than 20 h per week[13]. Other studies have reported a decrease in knee joint position sense following high-intensity isokinetic knee exercises[26]. The effects of high heels on knee joint position sense could be mediated by an increase in ankle plantar flexion angle and an associated larger range in vertical displacement of the center of gravity during walking[21, 25]. Another important component of decreased knee joint position sense might be muscle fatigue induced by increased gait velocity, which increases the number of strides per minute[26–28].

Overall, our results show that higher gait velocity and heel height induce a change in knee joint position sense, which negatively affect static and dynamic posture control. Future studies regarding the effects of heel height on lower limb proprioception and balance capacity are needed to evaluate age effects that would be prognostic of an increased risk for falls.

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