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The Impact of Shoe Heel-Toe Drop on Plantar Pressure During the Third Trimester of Pregnancy

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Abstract. Pregnancy induces various physiological adaptations to accommodate the growing fetus. Pregnant women commonly experience changes in gait, balance, and center of gravity, which may increase the risk of falls. This study investigates the effects of negative heel shoes on plantar pressure distribution during walking in third-trimester pregnant women. Twelve healthy primigravidas participated, wearing both flat shoes and negative heel shoes while walking. Plantar pressure data were collected using the Pedar-X® insole system. Results revealed that negative heel shoes significantly reduced maximum force in the medial forefoot regions compared to flat shoes, and the force-time integral only significantly decreased in the medial forefoot region. Wearing negative-heeled shoes resulted in an increase in peak force in the hallux region. The study suggests that modifying heel-toe drop in shoes can effectively mitigate plantar pressure during third-trimester pregnancy, reducing the risk of forefoot discomfort and potential injuries. Negative heel shoes could be beneficial for pregnant women, offering a solution to alleviate forefoot pressure and promote foot blood circulation during walking. However, further optimization is needed in the hallux region for negative heel shoes.

Keywords. Pregnant, shoes, heel-toe drop, negative heel shoes, plantar pressure

1. Introduction

Pregnant women undergo a series of physiological adaptations to accommodate the growing fetus [1]. These adaptations include hormonal fluctuations, anatomical restructuring, and physiological adjustments such as the redistribution of body weight, center of gravity shifted forward, and increased joint and ligament laxity [2-5]. These alterations affect the woman's postural control, requiring adjustments in body mechanics during gait [6, 7]. As a result, the musculoskeletal system must adapt to the changes that occur during pregnancy. Building new control strategies to maintain postural and gait stability, including the modulation of plantar pressure [8].

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Group of pregnant women chooses walking as their primary physical activity during pregnancy [9-11], but changes in gait, balance and center of gravity may increase the risk of falls [8, 12, 13]. Mei et al. investigated the biomechanics of gait during pregnancy and found changes in lower limb kinematics and plantar pressure. Specifically, they observed an increase in forefoot mean pressure [14], the lateral aspect of the foot experiences greater stress than the medial side, and the midfoot area also experiences increased pressure [14, 15].

There are many products available on the market to assist pregnant women during their pregnancy, such as specially designed shoes and insoles aimed at improving gait stability [16-18]. These shoes not only protect and enhance the natural function of the feet but also help maintain dynamic and static stability. The primary goal of current footwear design is to alleviate foot discomfort in pregnant women by altering the shape and materials of the outsole [19]. Jang et al. have designed incline shoes and reported their effectiveness in correcting posture and stabilizing gait patterns [20].

Negative heel shoes have a higher forefoot than heel [21]. Proponents of negative heel shoes can reduce lumbar lordosis, which shifts the center of gravity backwards [21]. It can also reduce back and hip pain [22]. The aim of this study is to investigate the effects of negative heel shoes on plantar pressure. This study can provide valuable insights and directions for designing shoes for third-trimester pregnant.

2. Materials and methods

2.1. Participants

The study involved twelve healthy primigravidas in third-trimester pregnancy. Participant's characteristics is outlined in Table 1. Participants with conditions such as lupus erythematosus, rheumatoid arthritis, gestational diabetes, hypertension, musculoskeletal or neurological abnormalities, or any other disorders affecting postural stability were excluded during recruitment [23]. All participants were informed about the purpose and significance of the study, and voluntarily signed informed consent forms. Ningbo University Human Ethics Committee approved the study.

Table 1. Participant's Characteristics

N=12	Gestation(weeks)	Age(years)	Height(m)
Mean	33.42	27.65	1.63
SD	4.16	4.62	0.12

.2.2 Shoe conditions

All participants in the study were wearing two types of shoes: the flat shoes and negative heel shoes (Figure 1). The control group consisted of commercially available flat shoes, while the negative heel shoes were custom-made in our laboratory using flat shoes as a base. Both types of shoes were identical in terms of material and overall design, except for the heel-toe drop.

Figure 1. Negative heel shoes(left) and Flat shoes(right)

2.3. Testing procedure

All participants walked as comfortable speed along a 10-meter corridor in a laboratory environment, while their data were collected using the Pedar-X® insole system (Novel, Munich, Germany). The sampling frequency was set at 50Hz. Prior to testing, the insole sensors were calibrated using a calibration system.

2.4. Outcome measures

Data was extracted from the Pedar system for each participant. Gait data from the right foot were selected, unless there was instability, in which case data from the left foot was used. The initial and final two steps of the data were excluded. Subsequently, three consecutive steps with stable and consistent gait were chosen. The foot was divided into eight regions as shown in Figure 2 [24]. Calculate the maximum force, contact area, and force-time integral for each region.

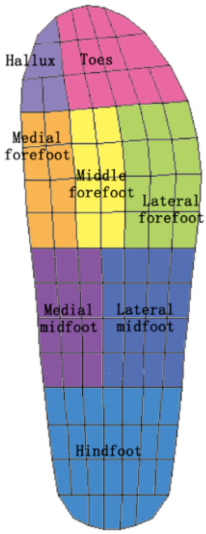

Figure 2. Eight foot regions for plantar pressure assessment.

2.5. Data analysis

The normality of the data was assessed using the Shapiro-Wilks test. Statistical analysis was conducted using SPSS 16.0 software (SPSS Inc., Chicago, Illinois, USA). The experimental data were presented as mean ± standard deviation ($\bar{X}$ ± SD). A t-test was used to analyze the difference in gait between negative heel shoes and flat shoes, with a significance level set at $P < 0.05$.

3. Results

The analysis results of maximum force in different regions are presented in Table 2. After conducting paired t-tests, it was found that compared to wearing flat shoes, wearing negative-heeled shoes significantly increased maximum force in the hallux region by 324.05N ($p < 0.001$, 95% CI = 226.07, 412.04), and in the medial forefoot region reduced 77.47N ($p < 0.025$; 95% CI = -149.31, -5.63). No significant differences were found in maximum force in other regions.

When wearing negative-heeled shoes, the contact area increased in the hallux, toes, medial midfoot, lateral midfoot, and hindfoot regions, but did not exhibit significant changes. During the third-trimester pregnancy, women wearing negative heel shoes showed significantly decreased force-time integrals in the medial forefoot region ($P < 0.005$, 95% CI = -45.34, -4.67).

Table 2. Mean different ($\bar{X}$±SD) of maximum force, contact area and force–time integral in each foot region

Region	Negative Heel Shoes			Flat Shoes		
	Maximum Force(N)	Contact area(cm2)	Force–time integral (N·s)	Maximum Force(N)	Contact area(cm2)	Force–time integral (N·s)
Hallux	375.80±78.60*	8.75±2.74	41.83±11.82	51.75±67.80*	7.63±2.81	58.21±11.54
Toes	143.60±35.10	9.81±3.58	41.52±12.37	148.30±48.60	8.42±2.15	37.81±19.41
Medial forefoot	138.48±38.60*	10.38±2.11	51.21±24.52*	215.95±56.34*	11.04±1.21	76.21±23.51*
Middle forefoot	164.52±83.52	17.86±3.37	39.12±15.80	198.86±78.51	18.62±1.17	41.52±17.53
Lateral forefoot	144.89±58.68	10.38±2.11	37.21±13.75	148.96±63.60	13.93±1.26	32.81±10.81
Medial midfoot	125.31±57.31	12.56±3.21	26.17±11.75	109.51±46.25	11.34±1.86	37.21±23.21
Lateral midfoot	98.67±54.20	21.53±4.35	13.27±9.21	84.68±57.61	20.87±3.86	12.14±6.91
Hindfoot	324.61±94.21	36.81±3.15	62.50±17.84	336.81±98.61	32.61±6.18	64.51±22.80

* Significant difference.

4. Discussions

This cross-sectional study aimed to analyze the effect of shoe heel-toe drop differential on plantar pressure distribution patterns during walking in pregnant women. The results indicate that pregnant women wearing negative-heeled shoes experienced a reduction in maximum pressure in the medial forefoot region, but an increase in maximum force in the hallux region. This suggests that modifying the shoes heel toe drop can reduce the medial forefoot pressure in late pregnancy, effectively mitigating the forces experienced during walking. The subsequent research will focus on the detailed investigation of various heel heights to calculate parameters such as plantar pressure, different foot regions, and the force-time integral.

The study found no changes in the average contact area, indicating no changes in the arch of the foot. Mei et al. noted that flattening of the medial longitudinal arch may lead to decreased stability during pregnancy [14]. Therefore, there were no significant differences in stability between wearing flat shoes and negative heel shoes in third-trimester pregnancy. In third-trimester, approximately half of the increased body weight is distributed in the abdominal region (anterior trunk) [25], leading to changes in the center of gravity and greater fluctuations in the center of pressure on the plantar surface [14, 26]. To compensate for this shift in the center of gravity, measures taken in third-trimester pregnancy include increased lumbar lordosis, sagittal plane pelvic tilt, and a more posterior tilt of the upper body [27, 28].

Ribeiro et al. reported that the load on the forefoot, in terms of maximum force and peak pressure, gradually increased as the load on the rearfoot declined [29]. Fatigue and midfoot injuries can occur in pregnant women when walking [30]. The structure of the forefoot is complex and its mechanical stability is inferior to that of the hindfoot. Prolonged or excessive loading can result in various pathologies. Reducing forefoot pressure during the support phase can help alleviate the risk of forefoot pain during pregnancy. Abnormalities in foot structure and function can lead to abnormally high peak pressures on the plantar surface. This can cause chronic overuse injuries related to impact forces involving cartilage and ligaments. Additionally, these abnormalities are closely associated with lumbar and back injuries and neurological disorders. This study indicates that wearing negative heel shoes can reduce forefoot pressure, effectively addressing the issue of elevated forefoot loading during walking in pregnant women and promoting blood circulation in the feet. However, we also observed an increase in peak pressure in the hallux region, this means further optimization of the negative heel shoes is needed.

5. Conclusion

This study investigated the effect of heel-toe drop differential on plantar pressure distribution in pregnant women, leading to the following conclusions: (i) Negative-heeled shoes reduce maximum pressure in the medial forefoot, potentially easing discomfort and lowering the risk of forefoot pain in late pregnancy. However, the increase in maximum force in the hallux region suggests that further refinement of shoe design is needed. (ii) No significant differences were found in the average contact area between flat and negative-heeled shoes during the third trimester, indicating that negative-heeled shoes do not impact foot arch stability. These findings emphasize the importance of considering body weight, shifts in center of gravity, and individual biomechanics in the design of footwear for pregnant women. Future research should explore various heel heights and continue to refine negative-heeled shoes to better address the biomechanical needs of pregnant women.

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