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Stilleto Type High Heel Shoe Design and Presesure Analysis with Adjustable Height

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ABSTRACT: Wearing high heels has been a consistent component in fashion trends for women in a variety of endeavors ranging from business to social settings. Research into the design of height-adjustable stilleto-type high heels is a response to shifting demands in the fashion industry. Consumer demand was not only focused on aesthetic appeal but also on comfort. Conventional high heels, especially the stiletto type, often had limitations in terms of long-term comfort due to their fixed height. This led to the need for innovative designs that allowed users to customize heel height according to their preference and comfort. This study presented the steps taken to develop adjustable high heels and analyzed how pressure was distributed on the sole of the foot. The pressure distribution on the soles of the feet while wearing adjustable high heels was measured using the FSR 400 device available at a shoe orthotics facility. The study aimed to develop an adjustable high-heel design that enhanced both fashion and user comfort through integrated design and pressure analysis. The manufacture of an adjustable high heel shoe model in this study was successfully completed by implementing an unloading system, where the heel featured two height options, 3 cm and 5 cm, and a screw-based locking mechanism. The subject of this research was was a 20-year-old female Mechanical Engineering student at Diponegoro University, with a shoe size of 39, a height of 159 cm, and a body weight of 45 kg. Test results revealed that heel pressure decreased as the heel height increased.

KEYWORDS: Adjustable; distribution; high heels; pressure; shoe; stilleto

1. Introduction

Wearing high heels had become a consistent component of fashion trends for women in various endeavors, ranging from business to social environments. Most women believed that wearing high heels provided a sense of confidence and psychological well-being. Based on a quantitative analysis conducted by the American Podiatric Medical Association (APMA), 72% of 503 women wore high heels, and 39% of them did so regularly [1]. It was also reported that some women wore high heels for up to 8 hours per day while performing daily activities, such as standing and walking [2].

Over the past few decades, various studies had shown that prolonged use of high heels could lead to several negative health effects, such as body alignment issues resulting in back pain due to spinal curvature, leg or knee pain caused by uneven weight distribution in the lower extremities [3]. These issues ultimately affected gait patterns, including gait speed and mobility, as observed in gait analysis [2].

Several studies were conducted to examine the influence of high heels on gait. Previous research also reported a decrease in gait speed with increased heel height [4]. Although the walking rhythm increased with heel height, stride length and step length decreased [5]. When heel height increased, subjects tended to adopt a more cautious walking pattern due to the forward shift in the center of pressure. As a result, they walked faster to shorten the swing phase, leading to a higher cadence and reduced stride and step lengths. In addition, the ground reaction force in high heels was found to be 5% higher than in low heels [4].

Research on the design of height-adjustable stiletto high heels emerged in response to shifting demands in the fashion industry. Stiletto-type heels were more commonly used by adult women to support their appearance and keep up with fashion trends compared to wedge heels. Consumer demand focused not only on aesthetics but also on comfort. Conventional high heels, especially the stiletto type, had limitations for long-term use due to their fixed height. This created a need for innovative designs that allowed users to adjust heel height based on personal preferences and comfort.

This study was conducted because conventional stiletto high heels had limited comfort for long durations due to their fixed structure. One of the main limitations was the inability to adjust heel height. The design presented in this study addressed that by allowing variation in heel height to enhance comfort during extended use. The goal was to present pressure distribution measurements, which are also valuable for orthopedic doctors when advising patients on safe and comfortable heel heights.

Previous studies had explored customizable high heels through mobile apps tailored to user preferences [6]. In contrast, this study applied a threaded system design that allowed reassembly and was equipped with two interchangeable heel types of varying heights. This approach offered a practical solution to the growing demand for fashionable yet comfortable stiletto high heels.

2. Materials and Methods

In the design of this shoe, a disassembly system was incorporated using insoles made from Poron cushioning material, a material commonly used in the footwear industry for insole production due to its comfort and shock-absorbing properties. The design process for the customizable high heels was carried out using the SolidWorks 2020 application. The design included detailed renderings and engineering drawings for the heel variation components, with two heel height options: 3 cm and 5 cm. Additionally, the design featured an illustration of the shoe upper, which would be attached to the sole and integrated with the interchangeable heel components.

The outsole material selected for this shoe was plastic, specifically PVC (Polyvinyl Chloride), which is widely used in the manufacturing of shoe outsoles. PVC is formed by heating and molding plastic and is known for its sufficient strength to support the user's body weight and its resistance to pressure. However, it also presents several drawbacks. These include limited rigidity that may lead to deformation, brittleness at low temperatures that can result in cracking, the potential to soften when exposed to certain chemicals, the possible presence of toxic additives in the production process, and slow biodegradation, which contributes to long-term environmental concerns. PVC is characterized by its rigidity, brittleness in cold conditions, and chemical sensitivity. While PVC is durable and performs well, it can be somewhat slippery, particularly on wet surfaces. Despite these limitations, it remains a viable material for outsoles in terms of functionality and cost. The research methodology used in this study is illustrated in Figure 1.

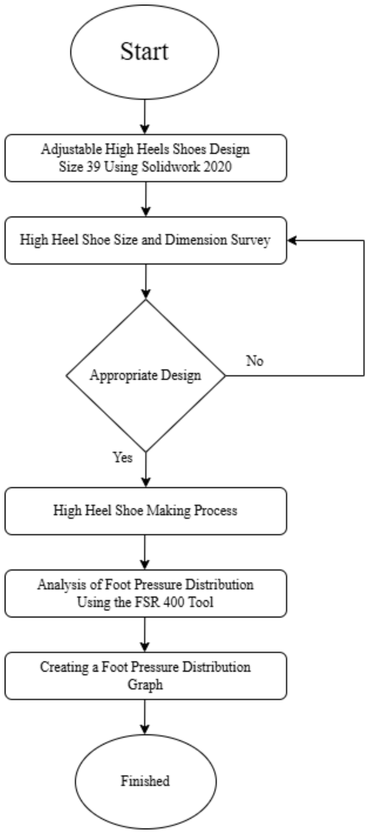

Figure 1. Research flow diagram.

3. Results and Discussion

3.1. Variation of adjustable high heel of stiletto type.

These high heels were designed with a special mechanism that allows the wearer to adjust the heel height according to their preference. Figure 2 shows the heel height variations of the adjustable high-heel shoe (stiletto type). The aim is to offer both comfort and flexibility, enabling users to adapt the shoe's appearance to suit different occasions, whether formal or casual.

3.1.1. Adjustable high heel shoe of 3 cm height.

Figure 3 presents the components of the adjustable high-heel shoe, which have been completed and are ready for use. This figure shows the first variation of the heel elevation mechanism. Each heel insert has the same diameter but differs in height. Specifically, the first variation features a heel insert with a diameter of 1 cm and a height of 3 cm.

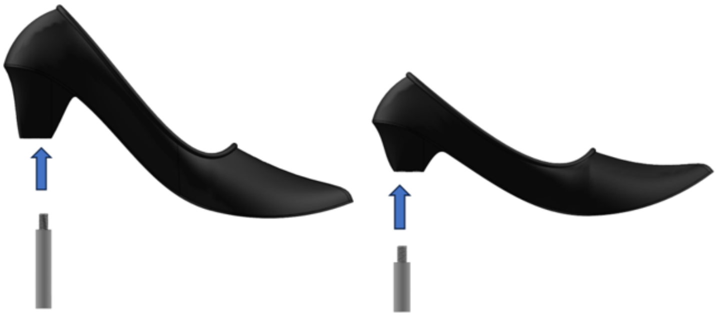

Figure 1. Assembly 2 variations adjustable high heel.

Figure 2. Variation of the first heel (shoe heel) measuring 3 cm.

3.1.2. Adjustable high heel shoe of 5 cm height.

Figure 4 shows the product illustration of the adjustable high-heel shoe component, which is completed and ready for use. This figure displays the second variation of the heel elevation mechanism. Each variation has the same diameter of 1 cm but differs in height. In this case, the second variation features a heel insert with a height of 5 cm.

Figure 3. A 5-cm shoe heel variation.

3.1.3. Adjustable high heel shoe of 6.5 cm height.

igure 5 shows the final product of the adjustable high-heel shoe, which is completed and ready for use. This shoe represents the first variation, with a total height of 6.5 cm. The variation consists of a combination of the upper shoe and a 3 cm heel insert. Each shoe variation uses the same upper shoe design, but the heel height differs to accommodate various user preferences.

Figure 4. Variation of the first shoe (high heel) with a total height of 6.5 cm.

3.1.4. Adjustable high heel shoe of 9.5 cm height.

Figure 6 presents the final product of the adjustable high-heel shoes, which are completed and ready for use. This shoe represents the second variation, with a total height of 9.5 cm. It is assembled from the same upper shoe as the first variation, combined with a 5 cm heel insert. Each variation shares the same upper shoe size, while the heel height differs to suit various preferences and comfort needs.

Figure 5. Variation of the first shoe (high heel) with a total height of 9.5 cm.

3.2.Analysis of foot pressure distribution using the FSR 400 tool.

The A total of nine sensors were used in this study, four placed on the forefoot (metatarsal area) and five on the rearfoot (heel area) [7]. The decision to place five sensors on the heel was based on the fact that this area bears the greatest load when a person is standing. Meanwhile, the four sensors positioned in the metatarsal area were intended to capture pressure changes when the heel height increases [8]. For pressure measurements, wedge-type shoes were used instead of stilettos, although the heel height variations were consistent with the design specifications. The visual layout of the sensors aligned with the local coordinate system on the force-measuring plate, as illustrated in Figure 7. All sensors were mounted on a 0.5 mm thick mica panel shaped to follow the contours of the metatarsal and heel areas of the foot [9, 10]. To enhance stability and comfort, a 0.5 mm layer of silicone rubber was placed beneath the mica panel.

The test device consisted of high-heeled shoes adjusted to shoe size 39, with heel height variations of 6.5 cm and 9.5 cm. The media casing is made of a wooden box made to protect the electronic circuit, including the Arduino and PCB, as well as a 1 cm diameter rubber hose used to protect the cable network. During testing, the sensor was placed on wooden wedges, at the same height as the shoe product that had been made. A USB cable was used to connect 37 circuit connections between the Arduino and the laptop used to run the test application [11].

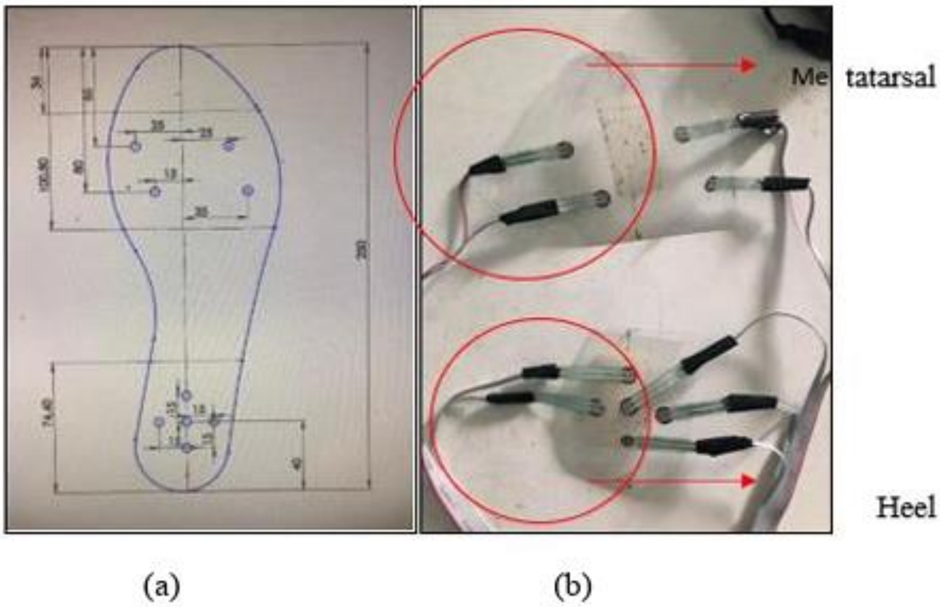

Figure 7. Prototype tool, a) Numbering and placement of sensors, b) Force measuring platform.

Each subject whose data was to be measured was asked to remove their shoes and socks to ensure adherence to standard procedures. To guarantee that the pressure recorded on the soles of the feet originated solely from the participant, care was taken to ensure they did not carry any additional load during the measurement process. It was also essential to prevent external disturbances from affecting the testing equipment. Data collection was conducted every 5 seconds once the subject was in an upright standing position, as illustrated in Figure 8 [12–14]. The results of the pressure distribution on the soles of the feet, measured using the FSR 400 device, are presented in Figure 9 [7, 15, 16]. In this figure, the x-axis represents the foot width (FW = 118 mm), and the y-axis represents the foot length (FL = 242 mm). Additional experimental data showing pressure values at varying heel heights are summarized in Table 1.

Figure 8. Illustration of testing on the subject's left foot at a shoe heel height of 5 cm.

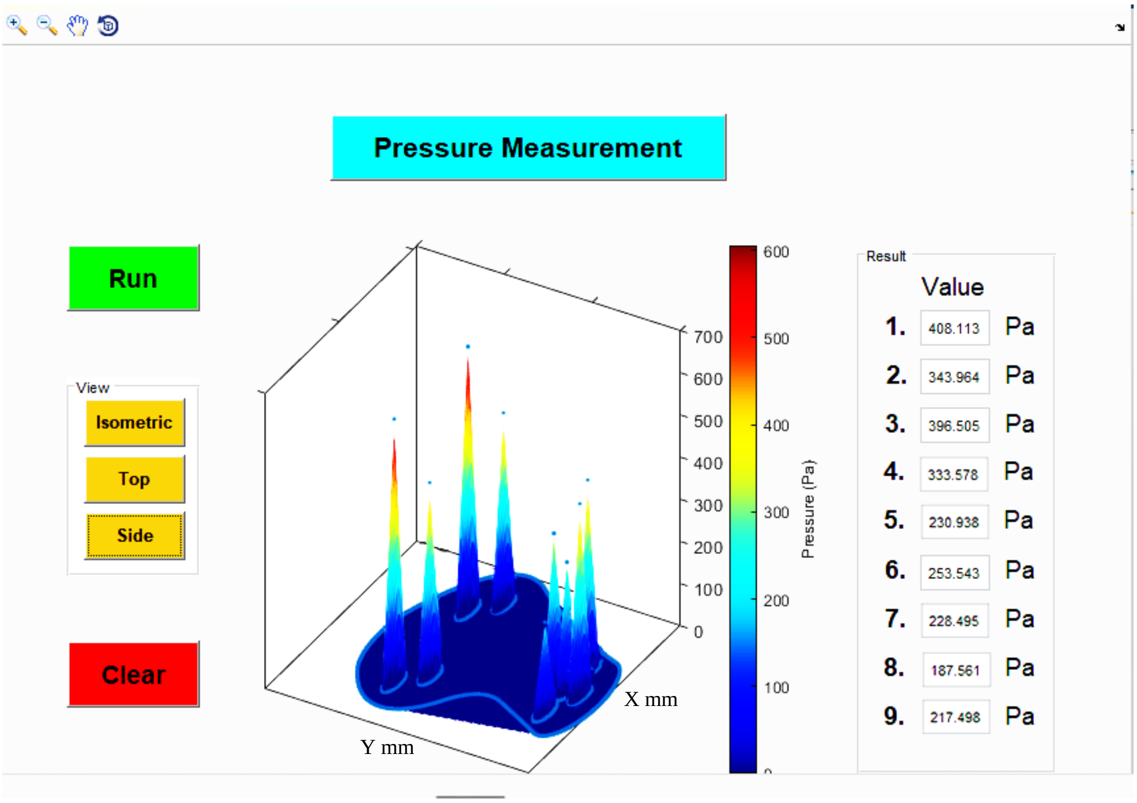

Figure 9. Illustration of pressure distribution at a heel height of 5 cm (left foot).

According to Table 1, when standing flat, the average pressure on the front sole of the foot was 140 Pa (18%), while the pressure on the heel was 609 Pa (82%). At a heel height of 3 cm, the average pressure on the front sole increased to 377 Pa (61%), and the pressure on the heel decreased to 240 Pa (39%). At a heel height of 5 cm, the average pressure on the front sole further increased to 620 Pa (82%), while the pressure on the heel dropped to 136 Pa (18%). The standard deviations for the left and right foot at each of the three heel heights are also provided in Table 1. In addition, the p-values comparing pressure differences between the left and right foot for each heel height are presented in the same table.

Table 1. Pressure distribution at each sensor at various heel heights (in Pa).

Pressure sensor #	Shoe heel height					
	0 cm		3 cm		5 cm	
	Left foot	Right foot	Left foot	Right foot	Left foot	Right foot
1 (data #1)	140.322	140.426	408.113	416.056	647.258	650.254
2 (data #2)	139.972	141.379	343.964	360.459	630.186	628.792
3 (data #3)	142.813	139.284	396.505	395.894	597.264	586.391
4 (data #4)	140.247	141.379	333.578	361.681	610.316	612.846
5 (data #5)	610.134	610.631	230.938	303.641	143.629	201.341
6 (data #6)	608.527	605.724	253.543	253.543	0	133.798
7 (data #7)	607.248	609.813	228.495	276.149	110.409	110.582
8 (data #8)	609.376	611.241	187.561	212.61	124.741	127.688
9 (data #9)	610.237	607.526	217.498	0	136.813	0
Standard deviation	246.801	246.859	82.496	126.936	276.580	271.537
P-value	0.417		0.469		0.408	

Thus, it can be concluded that with each increase in heel height, there is a pressure shift of approximately 22% from the heel to the forefoot. Secondly, as the heel height increases, the pressure on the front part of the sole increases, while the pressure on the heel decreases. This increased pressure on the forefoot observed in both heel height variations aligns with Lee Yung-Hui's findings, which suggest that rearfoot pressure decreases as heel height increases [8]. Another important finding from this study is that excessive heel height may cause the midfoot area to bend inward (concave), resulting in reduced contact with the insole. This not only decreases comfort but also compromises stability during walking [17, 18].

4. Conclusions

The conclusions drawn from this study are as follows. First, a prototype of adjustable high-heeled shoes was successfully developed using an uninstallable heel design, featuring two height variations of 3 cm and 5 cm. A threaded locking system was applied to secure the heel attachment. Second, the subject used for pressure distribution testing was a female student from the Department of Mechanical Engineering at Diponegoro University, with a shoe size of 39, aged 20 years, standing 159 cm tall and weighing 45 kg. Third, the results revealed that the findings are consistent with and support Lee Yung-Hui's theory, which states that heel pressure decreases as heel height increases. For future work, the study will involve more participants with different body weights and age groups to further validate and refine the shoe model. Real-world testing, such as walking on various surfaces, will also be considered to assess performance and comfort under more dynamic conditions.

Competing Interest

All authors declared that there is no personal, or professional relationships that might influence or appear to influence their research.

Auhor Contribution

Conceptualization: D.B.W., A.A.A.; Methodology: D.B.W., A.A.A.; Data Collection: D.B.W., A.A.A.;Data Analysis: D.B.W, A.A.A.; Validation: D.B.W., R.H.; Writing – Review and Editing: D.B.W., A.A.A., Y.A.; Supervision: D.B.W, R.H.; Funding: D.B.W.

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