A Study on Human Foot Pressure Behaviour and Balancing Characteristics

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Abstract. This paper presents an experimental investigation on pressure distribution on human foot and balancing characteristics on human foot health. Feet are the parts of the human body that will sustain the highest pressure during standing. Analysis of foot plantar pressure distributions helps in revealing the interface pressure between the foot plantar surface and the shoe sole. The objectives of this research are to study on behavioural of the human foot pressure distribution and balancing during standing. In this study, five factors are considered for the experiment to establish the behavioural of humans' foot, which are body mass index, gender, type of arch, diabetic and progressive foot deformity. Therefore, the experiment is conducted in order to know the pressure distribution based on factors by using Force Resistive Sensor. As a result, foot pressure distribution for normal subjects usually concentrated on the forefoot, followed by hind foot and middle foot. Body mass index also affects the pressure distribution as an increase in pressure follows an increase in body mass index and vice versa. As for gender factor, there is no significant difference in the pattern of pressure distribution between males and females. While for the type of feet arch factor, the different arch will give different locations of peak pressure. The diabetic factor, pressures will distribute more to the metatarsals and heel area while for progressive foot deformity factor, the pressure is usually distributed at the metatarsals and the toe area.

1. Introduction

One of the interest research fields in biomedical engineering study is about the human factor due to the foot pressure distribution while standing, walking even running. This pressure distribution is essential to understand the effect on the human body and balancing criteria. In order to ensure the health is in good condition, advanced technology in biomedical engineering tries to invent something that can help to find the treatment for human illness. Human illness sometimes can be healed by knowing where is the root causes. This root causes usually can be determined by knowing the characteristics of human body parts. By knowing the characteristics of the foot with the help of engineering studies, the suggestion of solutions or diagnosis for human health can be made. Feet are the foundation of the human body, which means keeping the feet healthy can help to keep the human body healthy. Measurement of foot pressure distribution (FPD) is useful to identify anatomical foot, evaluation of foot and gait pathologies [1]. Feet are the parts of the human body that will sustain the most and

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highest of pressure during standing. Pressure force distributions that are over the sole of the feet are not even as some forces will be distributed to every other part of the soles. As the foot is having contact with the ground, a reaction force will act upwards towards the human body. When all the forces over every part of the sole are average together, the forces are represented as the centre of pressure [2]. It is common to see human encounters foot problems due to wrong choices of footwear and sometimes work condition such as working in factories that requires standing. The first sign of wrong choices or unsuitable of footwear is when the shoe soles are frequently dented or broken in a short period time from the first time the person wears it. The worse effect from this can lead to shin splints, heel spurs and plantar fasciitis, iliotibial band syndrome, stress fractures and some other foot effects [3]. There are lots of foot diseases caused by pressure distribution on foot. Such disease is sometimes can be prevented early if the people understand about foot pressures. Therefore, this study is done with the intention of helping people to know their foot pressure distribution during standing. The intention of this study is about understanding the dynamic force distribution behaviour on human foot, identifying the pressure and force distribution of human foot at different selected point of foot such as big toe, metatarsal and heel, designing and implementing the device used to measure the distribution force of human foot by using pressure sensor and microcontroller Arduino Mega [4] . Then evaluation and validation will be done based on the results in this study. From this study, people can find solutions to their foot problem by using engineering and medical approach.

2. Methodology and Experimental Set-Up

The study of behavioural foot pressure is related to foot pressure distribution and balancing during standing. The first step is to understand the method of fabricating foot pressure device. The second step is to identify the location of the foot, which will be considered for the fabrication of the device. After knowing how to fabricate and which location to be chosen, the device can be built. The third step is to implement or experimenting with the device on subjects based on the factors involved. The data will then be collected and to be analysed before proceeding to evaluate and validate the results. Foot pressure distribution is affected by several factors. Hence for this study, five factors are to be considered for the experiment. The five factors affecting the behavioural of the human foot, such as body mass index (BMI), gender, and diabetic are shown in Figure 1, type of arch and progressive foot deformity are shown in Figure 2 are discussed next. Body mass index (BMI) is the anthropometric height/weight characteristics in adults and specific group of ages [5]. In general term, BMI represents an index of an individual's fatness [5]. The BMI is measured by specifying the height and weight of a person. Based on the World Health Organization (WHO) [6], gender refers to the socially constructed characteristics of women and men. In this study, both genders are used, which are students in the School of Mechanical Engineering. Diabetic is a chronic associated with abnormally high levels of glucose in the blood [7]. Figure 1 shows the sampling of diabetic patients. Ten diabetic patients are asked to step on the pressure sensor device in Figure 3 for data collection.

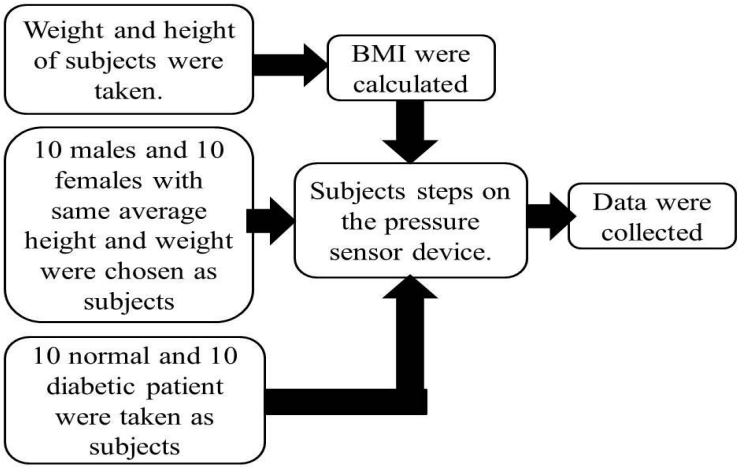


Figure1. Process flow for BMI, gender, and diabetic subjects to be measured.

The effect of foot arch on plantar pressure distribution is one of the factors that is investigated in this study, as shown in Figure 2. Based on the previous [8] in foot arch characterization, there is no doubt that the shape of a foot arch is useful for generating a proper-fitting shoe, however, the claim shows that the type of arch is more important and highly variable shape of the human foot which provides necessary shock pressure distribution for the foot during standing activity [8]. For the type of arch factor, few subjects are asked to dip their feet into a bucket of water and stamp it after onto a paper to see the pattern of their arch. After getting each about five sample of different type of arch, the subjects chosen are to be tested on the foot pressure device. Hallux Valgus is a scientific named [9] and refers to the progressive foot deformity commonly called a bunion as shown in Figure 2(b) with the red circle, is where there is medical deviation of the first metatarsal and lateral deviation of the big toe. In this study, the sampling persons with Hallux Vargus foot were taken [10-11].

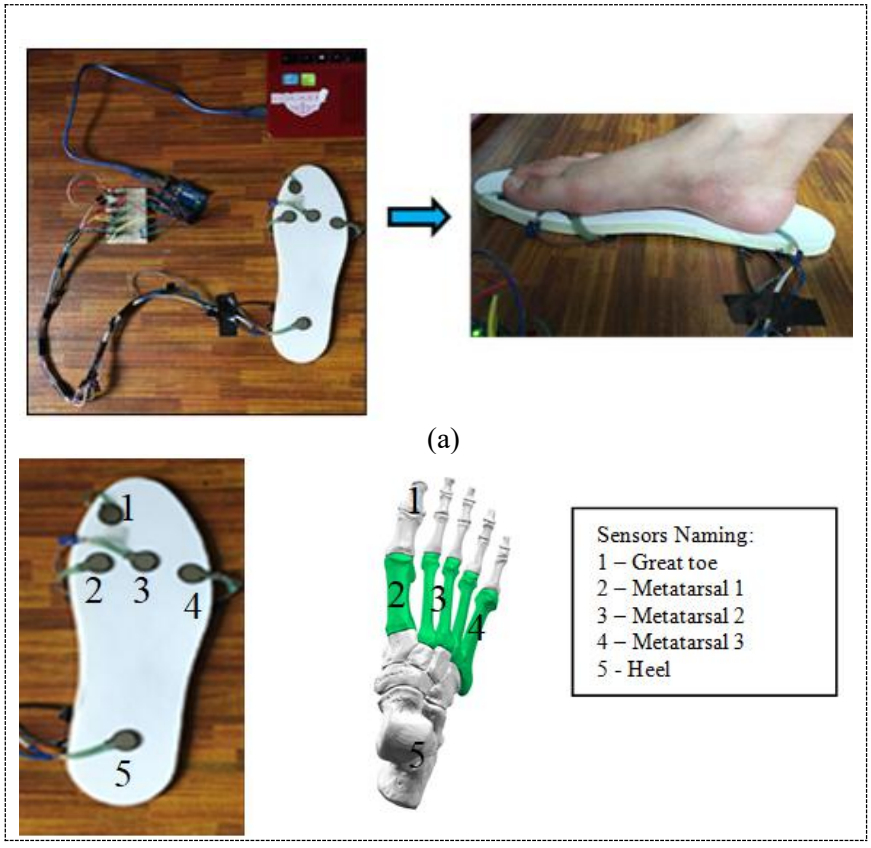
(a) (b)

(c) (d)

Figure 2. Samples of the pattern of foot arch from three subjects. (a) Flat, (b) Hallux Valgus, (c) Normal, (d) High.

3. Experimental Set-Up

The chosen subjects based on the factors stepped on the foot pressure device to take the reading of the foot pressures. The positions of the pressure sensors [12] are varied based on the subjects' foot size. Figure 3(a) shows the experimental set-up in this study, then how the data was collected when subjects step on the foot pressure device [13-14]. The pressure sensor will be taken at different location on the foot for the study. In addition, Figure 3(b) also shows the location of five sensors used for the study. The first sensor is located at the big toe, the second at the first metatarsal, the third sensor at the second and third metatarsal, the fourth sensor at the fourth and fifth metatarsal and the fifth sensor at the heel.



(b)

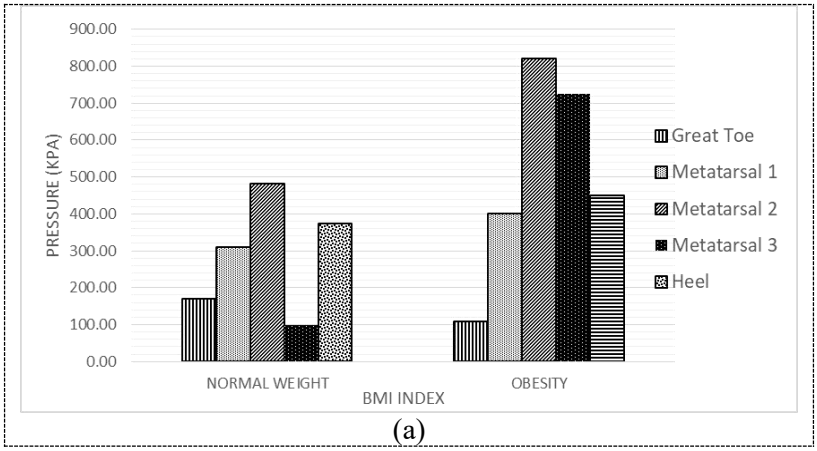
Figure 3. (a) Data were taken on one of the subjects and (b) sensors location on the foot [13].

4. Results and Discussion

Figure 4(a) shows the results of the subject's foot pressure data from five locations from the foot, which are the great toe, metatarsal 1, metatarsal 2, metatarsal 3 and heel were taken. Two BMI categories were considered in this experiment which is obesity and normal weight. Based on the results, BMI of obesity and BMI of normal weight are shown a lot of significant different pressure. These results prove that with high BMI, which is obesity index, the pressure in four locations, which are metatarsal 1, 2, and 3, respectively and heel were higher compared to normal BMI. Nevertheless, the great toe is lesser in obesity BMI than normal BMI, this is because the obesity person opts to stand and major of the load distribute higher to others four locations on the foot to make sure that the obesity person able to stand with normal distribution to support their body weight during standing [16]. In addition, the average results for subjects with normal weight and obesity category. It shows that for normal weight subjects, the pressure distributions during standing are found to be distributed over larger areas of the forefoot and heel. The highest average pressure is located at metatarsal 2 while for the lowest at metatarsal 3 for subjects with normal BMI. However, subject with BMI obesity, the foot pressure distribution is not uniformly distributed. The result shows a significant change in the contact area between the groups in the forefoot region. As for the obesity category, it shows a sudden increase of pressure located at metatarsal 2 and metatarsal 3. As the weight increases, the feet have to work harder to support the body and tissues in the feet as the feet are exposed to a greater workload [16]. The results of foot pressure based on gender are taken from 10 male and 10 female subjects. Only subjects with normal BMI of 10 male and 10 female subjects are taken for this factor. Based on the trend of the graph in Figure 4(b), it shows that men will have higher pressures in every location as compared to women. This is because men usually have more weight than women. However, the pattern of the graph for both men and women are said to be the same. Hence, there is no significant difference in term of pressure distributions between men and women. While for gender factor, men contact area was significantly larger in all regions of the foot compared with females. During the experiment, men have larger and broader feet than women. Male feet differed from female feet in a few characteristics, such as the arch, the lateral side of the foot, the hallux and the ball of the foot. The higher forces in a male may result of the fact that the arches in men are significantly stiffer than in women, thus dissipating the forces to be lesser. This proves that, the factor of gender is not a significant behavioural effect for pressure distribution in this study. Based on the Figure 4(c), the peak plantar pressure is significantly higher for diabetic patients compared to healthy subjects. The results for diabetic patient show a sudden increase at metatarsal 3, followed by great toe and metatarsal 2 and then metatarsal 1. The lowest pressure is at the heel for diabetic patient. While for normal BMI people, the highest pressure is still at metatarsal 2 followed by great toe, heel, metatarsal 3 and then metatarsal 1 [2]. For diabetic patient, a sudden increase in metatarsal 3 shows that diabetic patients can easily diagnosed foot problems due to unbalance pressures distributions. Besides, the pressures at metatarsals 1 are also high which means the location is also experiencing high pressures. Hence, it is easier for diabetic patients to get ulcer at metatarsals locations. Subjects with three different types of arch which are flat arch, normal arch and high arch (refer Figure 2) undergo the experiment to check on the pressure of the feet. For type of arch factor, another pressure sensor is placed at a new location of the foot to be examined which is at lateral middle foot. The reason is lateral mid foot will give effects to flat foot and normal arch but not to high arch [8]. Based on the result in Figure 4(d), high foot arch, the highest pressure is at forefoot as compared to the other locations of the foot, since the arch is not touching the ground. This causes the subjects with high arch feet to feel pain at fore foot and rear foot. The average pressure of people with high arch foot is 810kPa. Subjects with high arch feet exert the

highest pressure at great toe as compared to flat feet and normal feet too. The second highest pressure is by metatarsal 1 then followed by the heel. Moreover, there is no pressure at lateral mid foot since the arch is not touching the ground. In the meanwhile, for subjects with normal foot arch, the average highest pressure is concentrated at metatarsal 2 and great toe. The range of pressure distributed at metatarsal 1 is almost the same as the range of pressure distributed at metatarsal 3. However, the range pressures of the heel are higher compared to metatarsal 1 and 3, which proves that most pressure is still distributed at the rear foot. The pressure distributed at lateral mid foot location for subjects with normal arch feet is also quite high during standing with the average of 500kPa. In addition, for subjects with flat feet, the body pressures are more concentrated on great toe and heel. Meanwhile, the pressures at 1, 2 and 3rd metatarsal region are in ascending value which means the pressure is increasing to the lateral mid foot area. As for flat feet, the average lateral middle foot pressures of the subjects are around 300kPa. By comparing the entire graph, it can be seen that the flat feet highest pressures still cannot beat high and normal arch feet [17]. This is because flat feet are actually postural deformity in which the arch in foot collapsed which arches are supposed to function as to support the weight of the body weight and spread the body weight to the weight-bearing points of the sole [2].

Forth factor is hallux valgus, as shown in Figure 4(e), the normal feet in this case, which means not having hallux valgus factor, the pressure will be distributed to great toe and metatarsal 2 are the highest. While normal feet pressure will be the lowest at metatarsal 3. For subjects with hallux valgus case, the highest pressure is distributed the highest at great toe and metatarsal 1. As for the heel pressure, the subject's foot pressure is almost the same as the average pressure of normal subjects. This is because, with hallux valgus, the person will have less contact surface on the forefoot than the normal feet which lead to less pressure at metatarsal 2 and 3 locations. In addition, the person feels pain and less function on these two points. To overcome this problem, a patient can be treated conservatively with appropriate shoe-wear modifications, orthotics, and bunion splints. Surgery is indicated for pain relief and appropriate counselling of patients and their expectations are essential [18]. Based on the overall results, it shows that usually, great toe is one of the areas of the foot which exert the most pressure. This is because the toes are in contact for about three-quarters of the ground and exert pressures similar to those from the metatarsal heads. Toes also play an important part in increasing the weight-bearing area during standing. For normal subjects, their foot correlation should show significant negative correlation between the pressures under the great toe and under each of the metatarsal heads. Such as if the load under metatarsal 2 decreases, the pressures under the great toe should increases.



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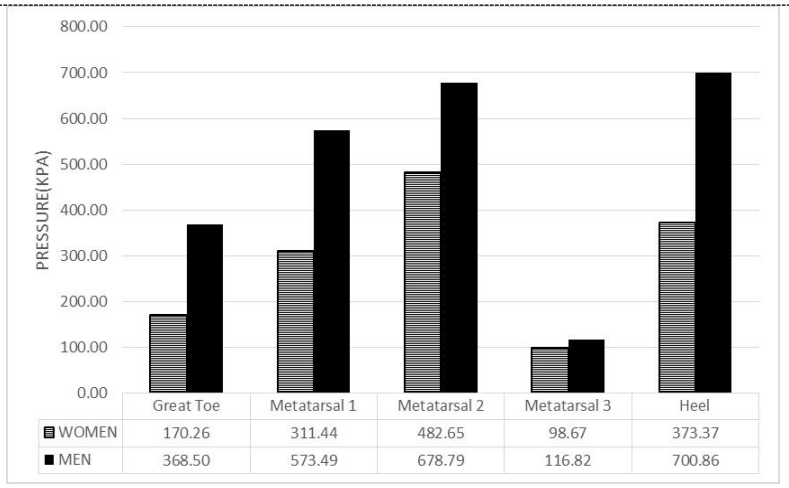
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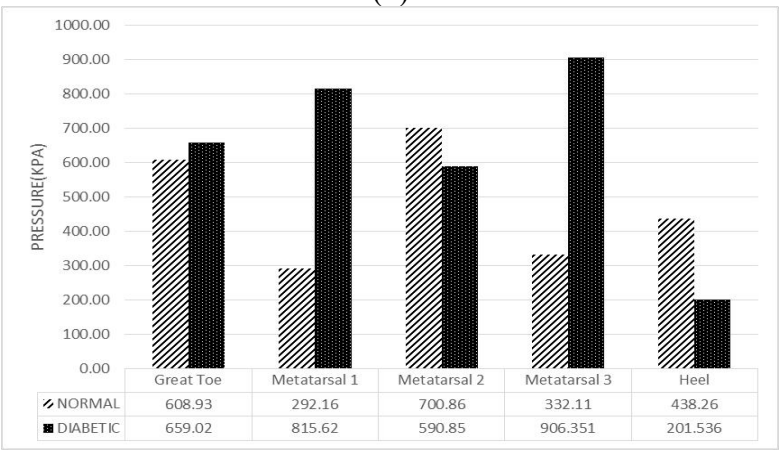
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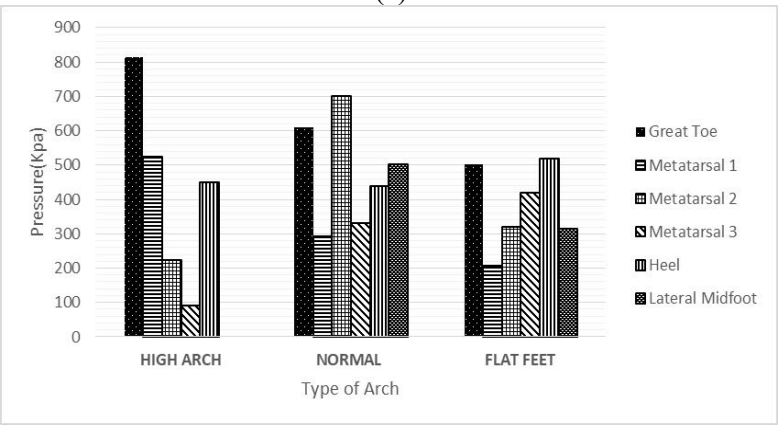
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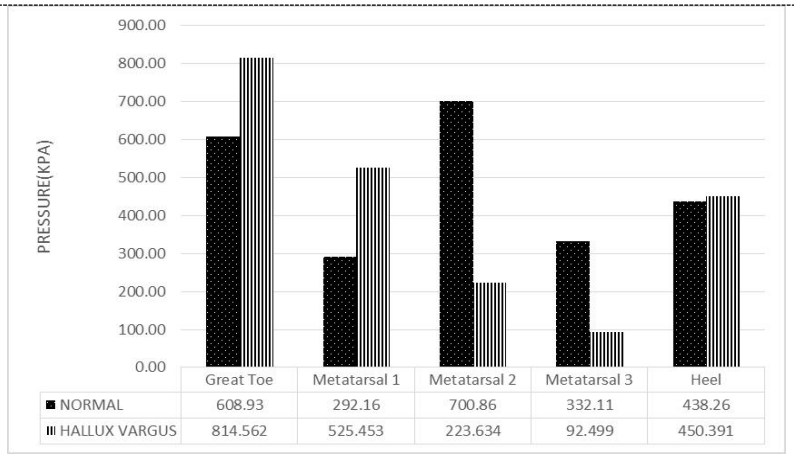

(e)

Figure 4. (a) Graph of the subject's foot pressure between normal and obesity. (b) Graph of subject's normal BMI foot pressure based on gender. (c) Graph of subject's foot pressure based on Diabetic factor. (d) Graph of subject's foot pressure based on type of arch. (e) Graph of subject's foot pressure based on Hallux Valgus factor.

5. Conclusion

Lots of factors has been affecting behavioural of human feet distribution during standing. Foot pressure distributions are distributed differently according to different factors. For normal subjects, forefoot usually to have more pressures distributed followed by rear foot then the mid foot. Body mass will lead to an increase in pressure due to overall load, concerning impact on the fore foot, mid foot and rear foot. As for gender, there is no significant different in pattern of pressures between males and females. However, the contact area of males is more significant than in females. There will be a variation of pressure distribution as the contact area for the foot of males and females are different. As for the type of arch factor, different type of arch will give different locations of peak pressures. Distribution of pressures on flat feet will concentrate on most of the parts of the soles since most of the soles are in contact with the ground. While for high arch feet, the distributions of pressures will distribute more at the forefoot and the rear foot but less to no pressures at all at mid foot. The highest peak and mean plantar pressures were found at the second and third metatarsal heads in healthy subjects. For the diabetic factor, pressures will distribute more to the metatarsals and heel area where the ulcers are usually developing. The fifth factor, which is the Hallux Valgus factor, pressures are usually distributed at metatarsals and great toe area since there are the presence of bunion.

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