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A COMPARISON OF PLANTAR PRESSURE DURING WALKING WITH BOOTS ON HARD SURFACE AND MUDDY SOIL

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ABSTRACT

Farmers wear agricultural boots during farm activity to protect their feet from diseases and injuries. Uncomfortable boots and their misapplication result in unexpected physical side effect. The purpose of this study was to determine the plantar pressure by using force sensing resistors (FSRs) and compare the pressure during wearing agricultural boots walking on hard surface and muddy soil. The plantar pressure can be detected by FSRs at four different positions of foot: toe, the 1st metatarsal, the 5th metatarsal and heel. The results showed that the pressure exerted on respective positions of the left foot for the hard surface were 137, 85, 45 and 95 kPa, and those of the right foot were 135, 146, 40 and 93 kPa, respectively. On muddy soil, the left foot pressures showed value of 90, 98, 130 and 845 kPa, respectively, and the right foot pressure were 36, 1150, 22 and 400 kPa, respectively. These results suggested that, for both feet, the pressures at each sensing position were not markedly different for hard surface. In the opposite, some extreme values of pressure were found at particular positions for muddy soil. The highest pressure of the right foot on muddy soil was at the 1st metatarsal and at the heel for the left foot.

Keywords: Plantar pressure; Agricultural boots; Hard surface; Muddy soil

INTRODUCTION

Walking is a kind of human locomotion to take the body forward [1]. The gait cycle starts from the heel contacts the ground to when the same heel again contacts ground. The pace cycle consists of two steps as stance and swing phase. To consider, stance phase begins with one side of heel, for example the right heel that contacts the ground is called heel-strike then the whole foot put down onto ground and the path of movement continues until the toe get to lift off that is called toe-off. When the right toe-off, the left heel will strike suddenly. The ground contact area occurs on both feet called double support. Then the right foot leaves over the surface, the swing phase will begin. And the whole left foot contact the ground with a single support, toe-off and right heel-strike are acted with double support again. The proportion of the stance phase approximately 60% of cycle and 40% for swing [1, 2].

The plantar pressure is defined as the pressure under the foot acts the ground [3]. The quantity of pressure depends on foot ground contact area, path of movement, human age, human mass, foot deformation and disease especially diabetics [4-6]. In clinical diagnosis, plantar pressure is important to diabetic patients, the physicians evaluate the ulceration affecting to sensory neuropathy with plantar pressure and pressure distribution in order to design the therapeutic shoes [5, 7]. In biomechanics, the scientists studied about kinetics and kinematics of body movement and floor that caused pressure with specific instrument. The force platform is a device to estimate pressure under foot, it is expensive and use only in laboratory [8, 9]. Since the force plate is large size the clinical company designed and it may make the insole measurement to insert in the shoes using outdoor. This device has many sensors, the cost is expensive too [3, 8]. Many researchers [7, 10-13] studied on piezo-resistive sensor that cheap and thin. The force sensing resistors (FSRs) were applied to measure force and plantar pressure including in laboratory and outdoor. The FSRs were used to evaluate the pressure in sport and exercise in order to design the suitable and comfortable shoes for athletes.

The most of footwear researches always study about sport shoes, high heel and diabetic

shoes using in daily life. A few of rubber boots researches are studied in clean room [14] or evaluated the slip on ice [15, 16]. In agricultural research, the scientists suggested to wear boots to protect foot from disease and pesticide [17, 18], and studied on allergy from boots' material [19]. There are hardly researches about using FSRs to measure the plantar pressure during walking with agricultural boots. Pathakamin et al. [10] used FSRs to compare the plantar force while walking with Polyvinyl Chloride and elastomer boots on hard floor. Therefore, the objectives of this study are to measure plantar pressure with FSRs and compare the pressure between walking on hard surface and muddy soil.

MATERIALS AND METHODS

Subject

A healthy 34 years old man, weighing 85 kg and 170 cm tall was selected for this experiment. In order to avoid the effect of walking pattern, the volunteer did practice to walk with a moderate speed of about 1.6 m/s [1].

Footwear

The Thai light weight agricultural boots that made of elastomer were selected. A pair of footwear was examined for hardness of the material at 4 zones including tread, platform height, instep and heel bone by pressing with digital hardness indicator (Desik Group, Germany) for 5 repetitions.

Surface

The two different surfaces: hard concrete surface and muddy soil were used in the test to investigate the plantar pressure when walking. The two outdoor walkways were 6 m long. The moisture content of muddy soil was determined.

Instrumentation

The measurement devices consisted of two main parts: detector unit and data acquisition unit. The main component of the detector unit was a set of force sensing resistors (FSRs) (Interlink Electronics, USA) connecting to the data acquisi-tion (DAQ). The FSRs were calibrated and the calibration equations are as follows:

$$y_1 = 2.8535x_1^4 - 14.837x_1^3 + 27.028x_1^2 + 32.896x_1$$
$$y_2 = 4.701x_2^4 - 27.814x_2^3 + 55.605x_2^2 + 8.7572x_2$$
$$y_3 = 1.9288x_3^5 - 18.471x_3^4 + 69.367x_3^3 - 109.54x_3^2 + 99.88x_3$$
$$y_4 = -0.3961x_4^5 + 6.4539x_4^4 - 25.369x_4^3 + 36.278x_4^2 + 42.041x_4$$
$$y_5 = 2.7643x_5^5 - 28.824x_5^4 + 111.75x_5^3 - 179.51x_5^2 + 159.85x_5$$
$$y_6 = 1.6578x_6^5 - 15.511x_6^4 + 158.984x_6^3 - 102.55x_6^2 + 125.27x_6$$
$$y_7 = 3.0034x_7^4 - 16.422x_7^3 + 34.872x_7^2 + 20.738x_7$$
$$y_8 = 3.0227x_8^4 - 19.673x_8^3 + 58.307x_8^2 - 25.992x_8$$

when y is the pressure (kPa) and x is the voltage (V).

The NI-USB 6009 (National Instrument, USA) was used for data acquisition associated with LabVIEW software which allowed recording, processing as well as displaying of the data.

Experimental procedure

Many researchers studying about plantar pressure in human daily activity reported that the pressure under foot of healthy subject will peak at 4 studied positions i.e. heel, 1st metatarsal, 5th metatarsal and big toe [7, 11-13]. Therefore, in this study the FSRs were mounted at 4 positions i.e. big toe, the1st metatarsal, the 5th metatarsal and heel on each foot as shown in Fig. 1. After that, the subject should be careful to wear agricultural boots to avoid damage of their wires. The subject did walk practice before testing to have skill enough to keep wal-king speed constant. Then the subject stepped on the hard concrete floor, the voltage signals that detected by sensors would be transmit to DAQ to show and record in computer. After the hard surface testing, the condition was changed into muddy soil and the same experimental would repeat again.

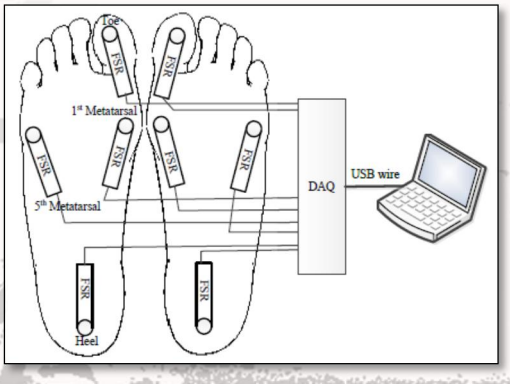

Fig. 1 A schematic diagram of the instrument

RESULTS AND DISCUSSION

The agricultural boots were physically observed as rigid material, inelastic and formed by injection. After measured hardness on 4 positions, the data was analyzed with statistics as shown in Table 1. It was found that the highest hardness was at heel bone and showed no significant value with one of platform height whereas lowest hardness was at instep.

Table 1 The hardness of agricultural boots

Region	Mean hardness (Shore A)±SD
Tread	44.5 ± 3.4b
Platform height	49.2 ± 3.4c
Instep	37.0 ± 5.0a
Heel bone	50.2 ± 1.1c

[a,b,c]Different letter indicate significant difference at 0.05 level

To consider the pace of each leg, as shown in Fig. 2(a) the heel of left started to contact floor with double support caused plantar pressure peaked at 0.4 s at about 95 kPa. Then the whole left foot put on hard surface completely at 0.3 s and continue until at 1.3 s, the plantar pressure on the 1st metatarsal and the 5th metatarsal were detected by the FSRs which were the highest at 85 and 45 kPa, respectively. At the toe that the last path of center of pressure was peaked at 137 kPa, the right heel reached the surface and the plantar pressure occurred in right leg.

Fig.2.(b) showed the right leg took the first step like the left and the peak pressure of heel was 93 kPa at 0.3s. The single support phase of right foot began and ended from 0.2 to 1.4 s, the 5th metatarsal was 40 kPa and less than the others in the forefoot. The plantar pressure at the 1st metatarsal position was the highest value with 146 kPa. At the final step of pace, the pressure at toe was found 135 kPa.

The pressure trends of both feet were similar but the highest value on right foot was 1st metatarsal whereas was at toe on left foot.

The plantar pressure when walked on 60% of average moisture content of muddy soil (64% of sand, 9% of silt and 27% of clay) represented in Fig. 3(a) and (b). The results were vastly different from walking on the hard concrete surface.

In Fig. 3(a) the pressure under the left heel was 845 kPa that was the highest value and 8.9 times higher than at same position when walked on hard surface. Moreover, total time for left stance phase was 60% more than in case of walking on hard. The forefoot pressure at the 5th metatarsal was a little bit higher than 1st metatarsal and toe expressing by 130, 90 and 98 kPa, respectively.

The plantar pressures on right foot displayed in Fig.3.(b), the pressing force beneath heel continuously rose until 1.5 s and then nearly stabled at 400 kPa for 2.5s. Then the path movement forwarded into mid-foot and for-efoot, the curve shown the highest peak pressure was about 1150 kPa at the 1st metatarsal position, which was 7.9 times when compared to one at the same position on the hard surface. The 5thmetatarsal and toe were distinctly lowest value in forefoot region about 22 and 36 kPa.

Complete step of walk on muddy soil took 4.6 times longer than that of walk on hard surface.

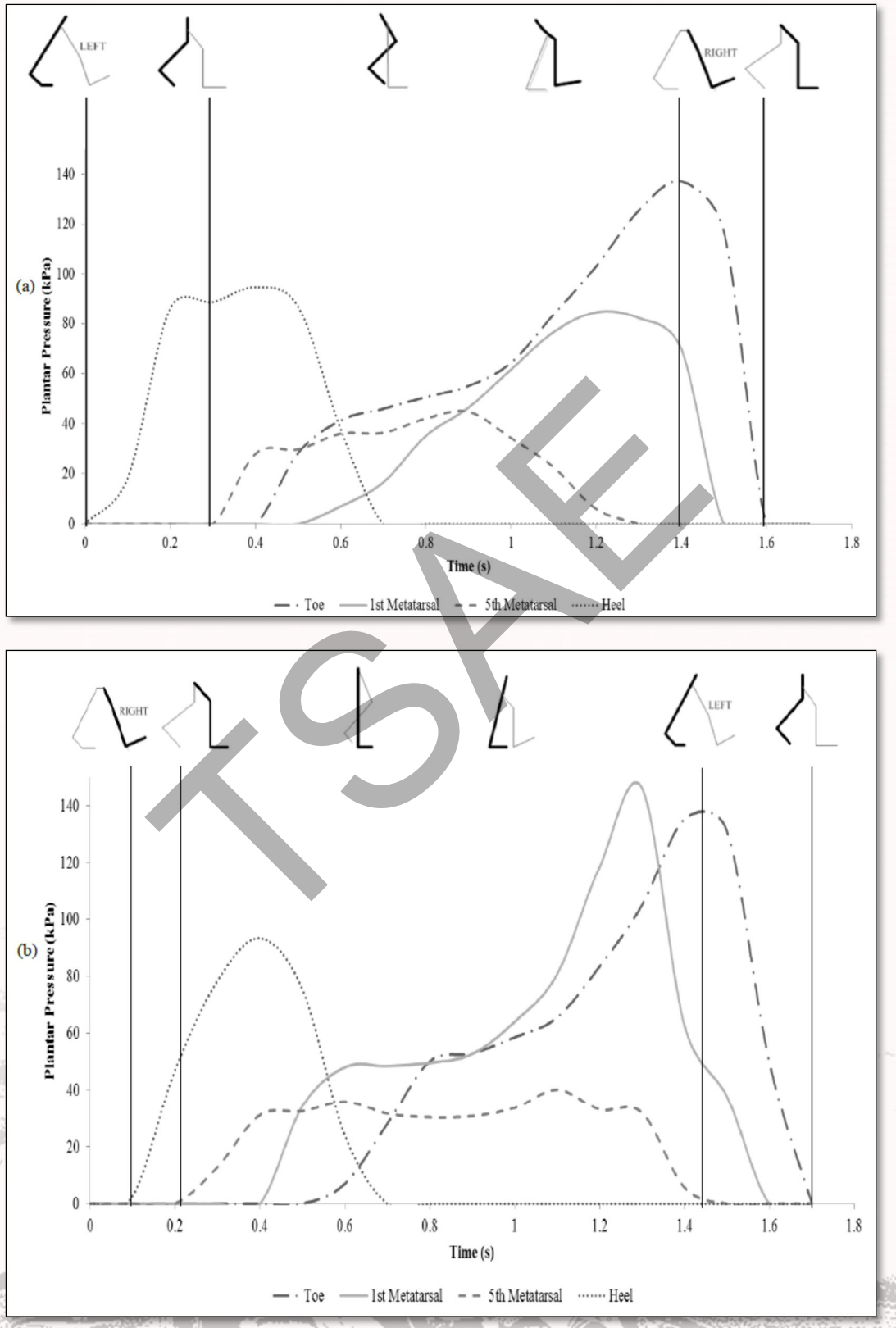

Fig.2. The plantar pressure during walking on the hard surface (a) Left (b) Right (a) (b)

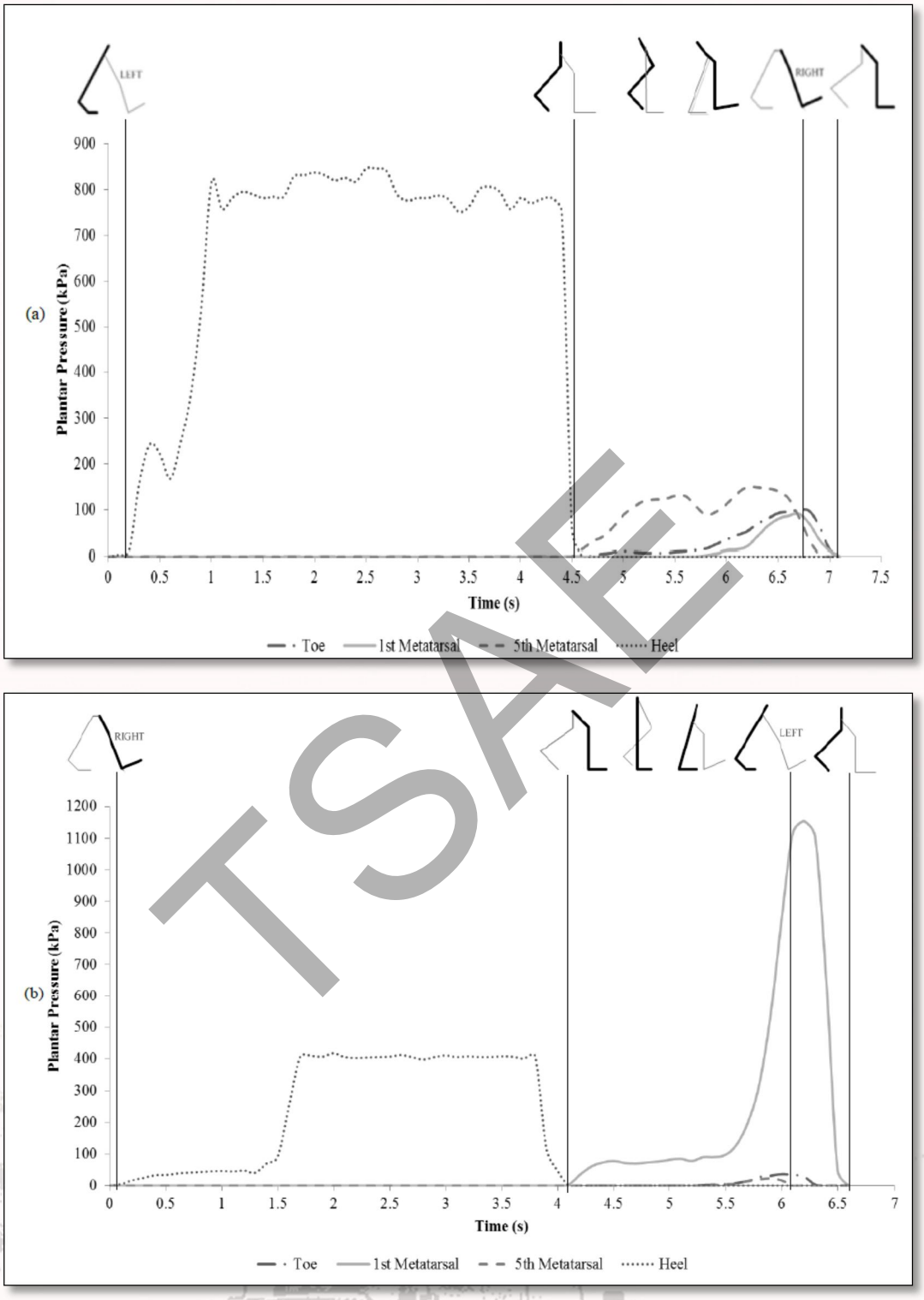

Fig.3. The plantar pressure during walking on muddy soil (a) Left (b) Right

After walking, the volunteer was asked for comfortability for wearing agricultural boots to walk on both surfaces. The results appeared that the boots were firm and comfortable to walk on hard surface. On the other hand, they were not comfortable to walk on muddy soil, for example when stepped on and lift up it may cause slippage and unsteady balance. In each step, the volunteer overexerted to uplift the boot from soft soil because of muddy soil adhesiveness. This also submerged another boot into muddy soil and resulted in foot free from that boot. Therefore, in order to avoid foot free from boot or slippage, the volunteer have to move slowly and put more force on the heel to secure stability. From the observed data, the peak pressure occurred at 1st metatarsal on the right foot may be caused by that the volunteer was right-handed and by rigid material of instep compressing the bone. For continuing walk, this may also hurt around the 1st metatarsal region of the volunteer.

From the result, it seems that elastomer boots using in this experimental test is suitable for walking on dry and hard floor, but improper to use in wet and soft surface.

CONCLUSION

The plantar pressures when wearing agricultural elastomer boots walking on two surfaces were obviously different. On the hard surface, plantar pressures showed quite similar and low values for all positions of both feet. However, plantar pressure on muddy soil showed different tendency. There were peak value of 845 kPa at heel for left foot and 1,150 kPa at the 1st metatarsal for right foot. The values were 8.9 times higher and 7.9 times higher at the same positions for left and right feet, respectively.

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