Data Acquisition and Analysis in Biomechanics, Ergonomics, and Sports

The impact of shoes and gait type on the plantar pressure

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ABSTRACT

Movement is one of the most important things in human life, and the way that we move can affect us in several ways. Since the feet support the whole body the foot function during the movement, in different conditions, will be analyzed through the plantar pressure. This work is based in three different hypotheses: the plantar pressure when barefoot is higher than when with shoes on, it increases with the speed of the gait, and the male and female plantar pressure are different. The results for 3 subjects (2 male and 1 female) showed that the first and second hypothesis were confirmed, although the maximal force and peak pressures, when wearing shoes, were lower than the expected. About the third hypothesis the results are not significative because of the lack of representativity in this study. In the future a more significant study about the differences in plantar pressures for male and female could be done to understand the possible consequences of it.

1. Introduction

In daily life humans do not always move in the same way, they walk, run, sometimes walk barefoot, etc. And each different movement will have a different influence on the body, that is why it was decided to study the influence of each movement on the plantar pressure.

The plantar pressure is the pressure field that acts between the foot and the support surface during our movement [1]. Using the plantar pressure measurement, it is possible to analyze the foot function during the gait and can help in the posture research. Human walking can be described as a cycle which is composed by two phases, the single support, and the double support. As the name suggests, the first one is when one leg is supported on the ground and the other one is swinging , the second one starts when the swinging leg meets the ground and ends when the support leg leaves it. It is necessary to note that when running just one leg is on the ground at a time [2]. A full gait cycle begins at the heel strike of one foot and ends with the heel strike of the same heel in preparation for the next step.

It is possible to find a variety of themes studied through the plantar pressure. For example, there are several papers about the influence of obesity [3], or about the influence of diabetes in it [4]. Beyond the therapeutic studies the analysis of the plantar pressure is also useful to find the best insole properties and the best shoes for different sports.

In this work it was done three different study subjects who performed different activities to be evaluated. The point of the work is to answer the following questions:

It is best to walk with or without shoes? [5]

What are the differences that the feet suffer when running instead of walking? [6]

And in the end, there is any difference between a female's and a male's plantar pressure? [7]

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2. Methods

As it is known, gait is one of the most frequent form of movement and it has to be analyzed very accurate as it implies the musculoskeletal and neuronal systems and once there are some perturbations in the gait it is needed to answer these questions: "why this perturbations appeared? Is it due to the neuronal system or the musculoskeletal one? What can be the negative effect of these perturbations? How can we avoid these perturbations?".

2.1. Data Collection

For a better analysis, it is recommended to have as many samples as possible and in different forms(standing, walking, running, jumping, with shoes, without shoes), with as many samples as possible we have at our disposal enough data to analyze and to come with a very precise verdict. Of course, just a bunch of qualitative data is not enough, we need knowledge to be able to explain the data.

In this mini research were recorded different movement forms from 3 participants using a wireless, in-shoe pressure measurement system (medilogic®, German) that can be seen in Figure 1.

Figure 1. The components of the Mediologic measurement system

To get the plantar pressure values the following steps were followed:

1. **Define insole size**

This step is very important as if a wrong insole size is chosen the recorded data may be uncomplete or overcomplete. To choose a right insole size is needed to know the shoe size of the test-person after that the specific equipment is tested as the corresponding size might be uncomfortable for the participant.

2. **Prepare test person**

After the right insole size was chosen, the test person must be equipped with according to the instruction as the cables does not bother and the insole size is placed correctly as a wrong placement of the insole size may cause wrong measurements. Also, the distance between the router and the participant has to be chosen accordingly as a very large distance may cause poor data transmission or if between the router, different objects between the participant and the router has to be avoided as those may disturb the signal transmission.

3. **Perform offset-measurement**

As it is known, the insole size, the socks, shoes may influence the output data and in order to be able to analyze the data measurements that really belongs to the test person it is needed to measure the offset which will be taken into consideration when further data analysis will be performed.

4. **Perform measurement**

After all previous steps were carefully made, it is time to start collecting the data. Collecting the data starts from the computer and it is transmitted wireless to the computer. For a useful measurement, each participant must do at least 6 sequences of movement (6 steps, 6 jumps, etc.). After the measurement is done, the recording should be analyzed to check if there are no errors during measurement, if the measurement was done correctly, the data has to be exported with an appropriate name for each participant, step, characteristics. The measurement frequency is 100 Hz.

5. **Second offset-measurement**

Before each measurement, the offset-measurement must be performed as it influences the data output. As accurate all the procedures are done as accurate the data output will be. Therefore, the analysis on accurate data may affect positively the findings and the conclusion.

Table 1. Participants' characteristics

	Gender	Height(m)	Weight(kg)	Shoe size(pp)
P1	Male	1,81	70	44
P2	Female	1,65	55	38
P3	Male	1,8	76	43

None of the participants had problems with the locomotion. Therefore, each result must be compared with the results of a normal human with the same characteristics or with a human that represent the closest cluster.

2.2. Data Analysis

During the measurement process it was possible to analyze real-time, 3D impact of the foot on the surface. At the disposal was a color scale, from blue to red, representing the power that acts on every sensor. The red color represents a very high power, more than 55 Newtons and the blue color represents a very low pressure.

After all measurements were done, the recording was checked and if the recording fulfilled the requirements, the data was exported to .CSV files. For each recording 5 files were generated:

Raw sensor file (_R.csv – right leg, _L.csv – left leg)

COP (_CYCL.csv)

Gait line (_GL_R.csv – gait line right leg, _GL_L.csv – gait line left leg)

Depending which insole size was appropriate for each participant, a specific number of sensors were in the insole, and for each sensor, the data is collected in each timeframe. A simple representation of the recorded data can be previewed in the Figure 2.

Sensor Number	29	30	31
Minimum	0	1	0
Maximum	0	2	1
20% Average	0	2	1
0	0	2	1
0,008	0	2	1
0,017	0	2	1
0,025	0	2	1

Figure 2. Figure 2. Representation of collected data from each sensor. (_CYCL.csv)

In the Figure 2, few timeframes are presented from the raw sensor file for the left foot.

Later, collected data was prepared for further analysis using MATLAB. Based on the data, the corresponding graphs were created to support the gaining of this study.

	A	B	C
1	Timestamp	X-coordinate	Y-coordinate
2	0	2147483647	0
3	0,008	2147483647	0
4	0,017	2147483647	0
5	0,025	2147483647	0
6	0,033	2147483647	0
7	0,042	2147483647	0
8	0,05	2147483647	0
9	0,058	2147483647	0
10	0,067	2147483647	0
11	0,075	2147483647	0
12	0,083	2147483647	0
13	0,092	2147483647	0

Figure 3. Representation of collected data for left leg for each sequence of time during the measurement. (_L.csv)

2.3. MATLAB analysis

To perform a correct analysis, we need two sets of data: offset and measurement.

The first step is to calculate the mean value of the offset for each sensor, then subtract it to the actual measurement.

Once this is done, the data's amplitude is converted in order to make it more understandable and usable. This operation consists in converting the bits originally measured, into a pressure in N/cm² using a simple linear coefficient. The measuring device runs on 8 bits (256 values) and can measure up to 64 N/cm². Therefore, the following equation should be used.

$$pressure = (datawithoutoffset/256) * 8 \quad (1)$$

After dealing with the vertical axis, it is also important to deal with the horizontal axis. The purpose here is to convert time, to percentage of the stance phase.

The first thing to do, is to shorten the measurement in order to delete all of the unwanted parts, such as the acceleration when the subject starts running, and keep only the regular stance phases. Once this is done, it is necessary to work on each stance one by one in order to gather all of them in one final graph, in which all the stance phases will appear superimposed with an horizontal axis going from 0% to 100%.

The final step of the MATLAB analysis is to divide this new graph with the different parts of the foot: toes, forefoot, midfoot and heel. This step consists in calculating average values of all the stances, as well as calculating the standard deviations. The Medilogic© system consists of several sensors (from 102 up to 157, depending on the insole size) and it is therefore possible to divide those sensors in different areas. Once this is done, the average values for all those areas should be calculated, as well as the standard deviation. This process makes it possible to see which parts of the foot are involved in the stance phase, when they are involved, and how much pressure is put on them.

3. Results

The following figures are the results obtained after the MATLAB analysis explained earlier, in the methods section. The full curves correspond to the mean values, while the dotted curves correspond to the standard deviation.

The units and values are specified on the axis, and the colors can be interpreted as follows:

- Toes' pressure is in cyan.
- Forefoot's pressure is in red.
- Midfoot's pressure is in green.
- Heel's pressure is in dark blue.

3.1. Participants' performances

3.1.1. Participant Nr. 1

In this section, the visualized data regarding the first participant performance will be displayed. The illustrations were created using MATLAB.

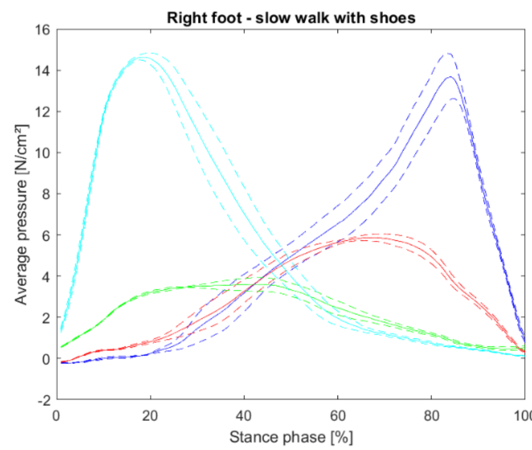

Figure 5. Graphical representation of the right foot plantar pressure during slow walk with shoes

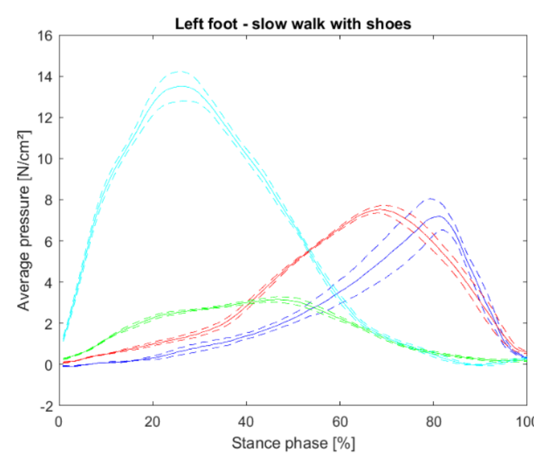

Figure 4. Graphical representation of the left foot plantar pressure during slow walk with shoes

As it could be observed in the above figures, during the slow walk with shoes, for the first participant, an asymmetry of Heel's pressure was recorded. Therefore, it can be concluded that this participant has specific deregulations regarding slow walk.

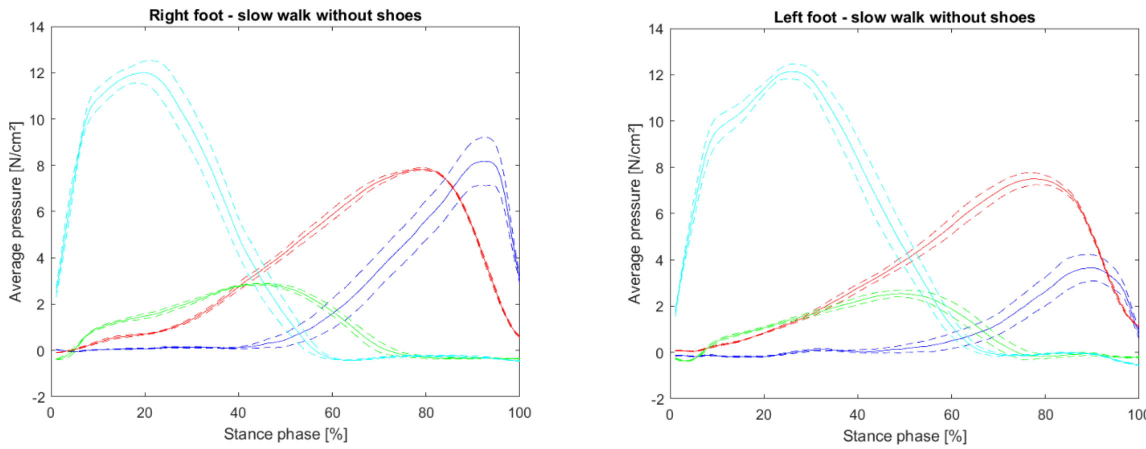

Figure 8. Representation of the first participant's feet performance, during slow walk without shoes.

Comparing the results of each foot is it possible to see that the heel's pressure varies between the left and right foot. Also, forefoot's pressure varies between the feet. Even though, toes' pressure is following the same pattern, for both legs, for the right foot, a higher pressure is recorded, the difference between the left and right foot is about 1.5 N/cm^2.

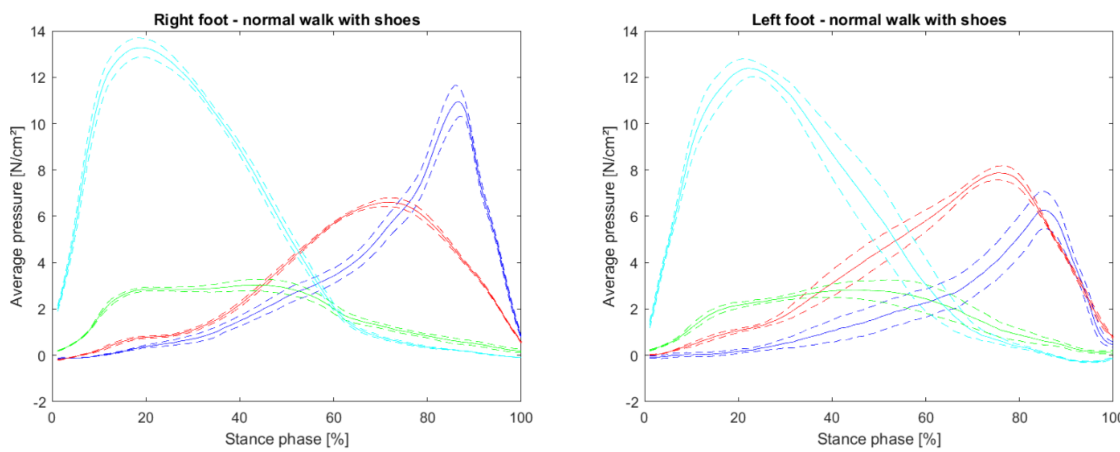

Figure 7. Representation of the first participant's feet performance, during normal walk with shoes.

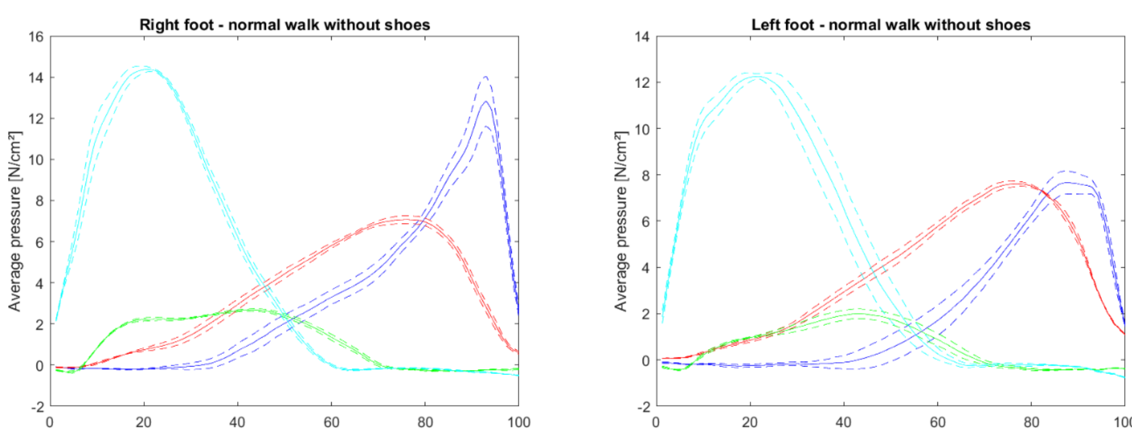

Figure 6. Representation of the first participant's feet performance, during normal walk without shoes.

After analyzing the performance during normal walk, with and without shoes, it is clearly distinguishable that there is an asymmetry between the feet. The asymmetry is characterized by a lower heel pressure of the left leg, this asymmetry can be observed during gait analysis in different ways. Regarding the toe's pressure, it is smaller for the left leg, comparing with the right one. This asymmetry can be explained as the fact that the participant has the right foot as the beating one. Moreover, forefoot's pressure, is recording an opposite pattern, greater for the left leg, fact that confirms once again the participant's characteristics.

3.1.2. Participant Nr. 2

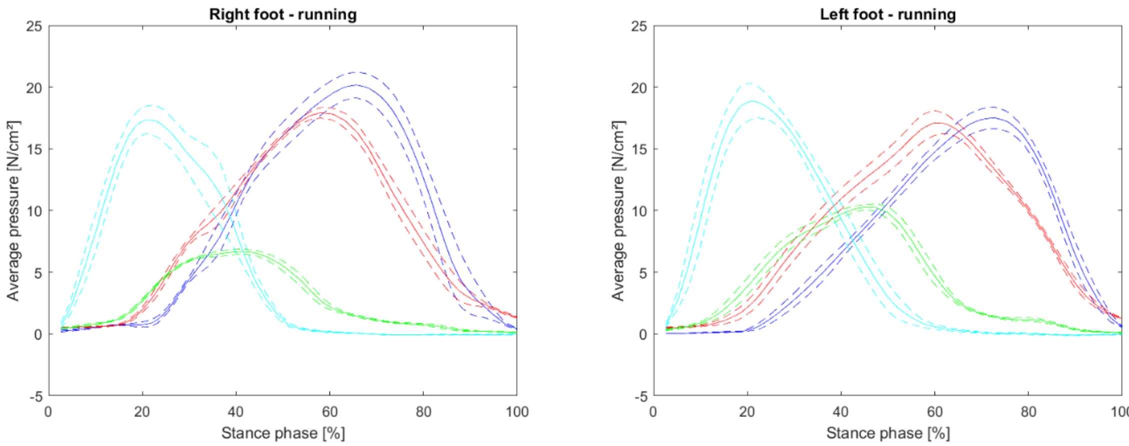

Figure 9. Representation of the second participant's feet performance, during the running process, with shoes.

For the second participant, both legs record, the same pattern regarding the plantar pressure, with an exception made by the heel and midfoot pressure, but the differences are quite small. An asymmetry during the running process is observed for the contact time, where the contact time of the left foot is longer. Also, the minimum and maximum plantar pressure are very close to the average.

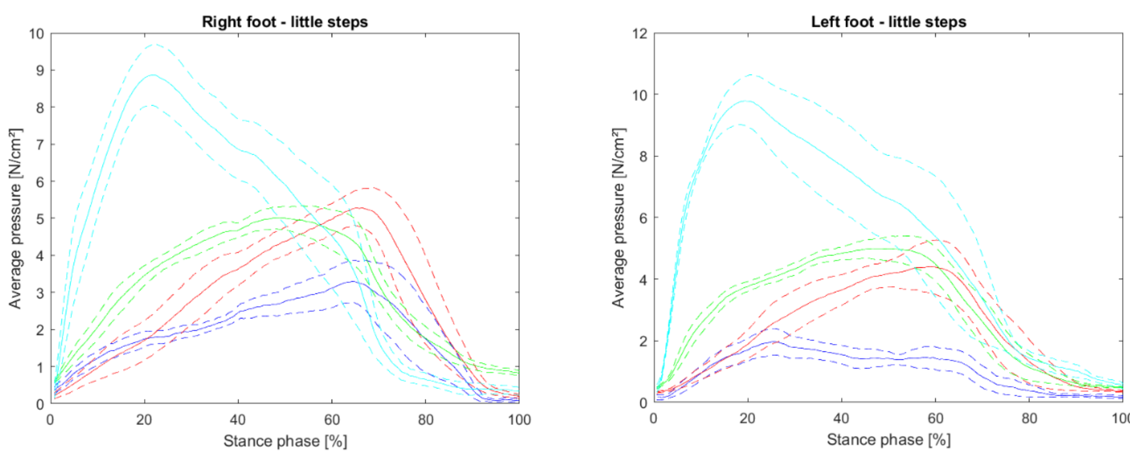

Figure 10. Representation of the second participant's feet performance, during the walk with little steps.

Regarding the walk with little steps, for the second participant, is it possible to observe that as it implies little steps, the contact period will have to be greater than during the running process or just normal walk. As we can see on the graphs, the pressure of each component (heel, forefoot, toe and midfoot) is recorded during the whole stance phase. At this point, an asymmetry of heel’s pressure can be observed. The other components record the same pattern with equal pressure.

Talking about the minimum and maximum of each component at each stance phase, it is clearly visible that there is a moderate dispersion, minimum and maximum being equally distanced from the average value.

3.1.3. Participant Nr. 3

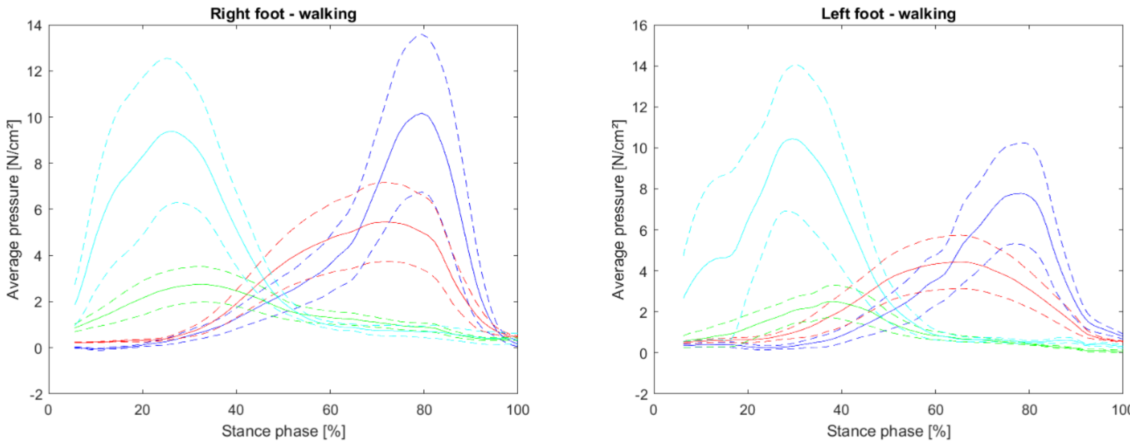

Figure 11. Representation of the third participant's feet performance, during normal walking process.

Comparing the results of the first participant with the third’s participant, for the same process, it is clearly visible high differences. The forefoot’s pressure of the second participant is almost all the time under the heel pressure, phenomena that is different for the first participant.

Moreover, beside the differences between participants (both male, same height, sole size), an asymmetry is clearly distinguishable.

Talking about the recorded signals, those are very distanced from the average value.

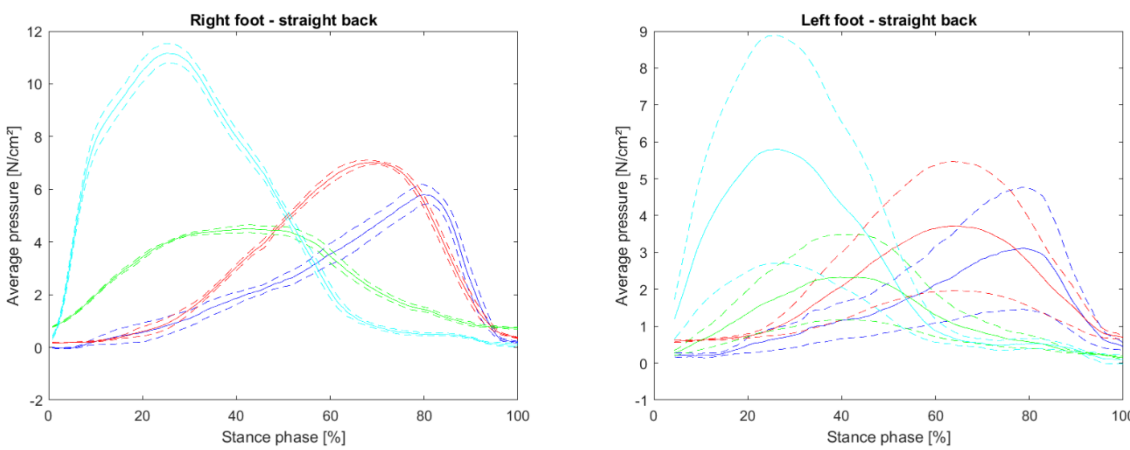

Figure 13. Representation of the third participant's feet performance, during straight back walking.

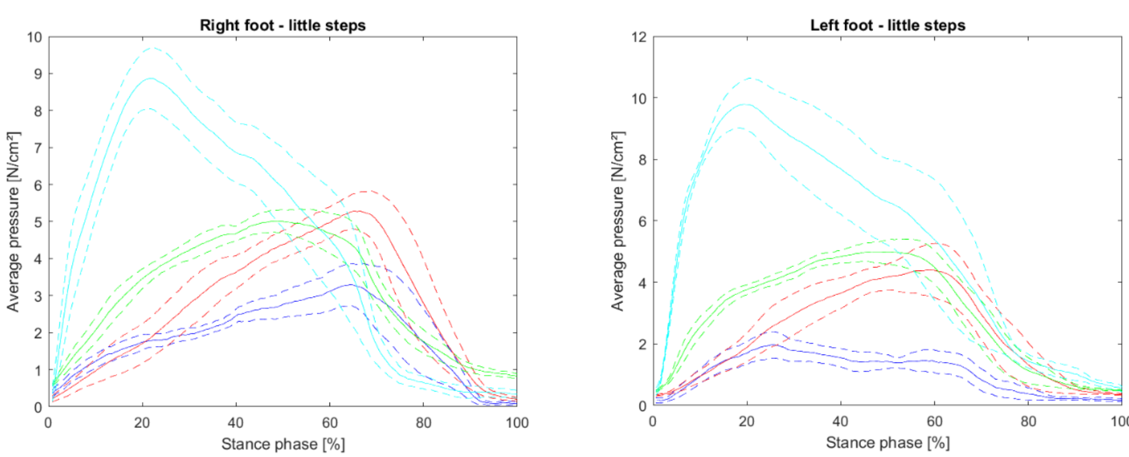

Figure 12. Representation of the third participant's feet performance, during walking with little steps.

4. Discussions

The purpose of this study was to investigate the influence of the shoe and the gait type on the plantar pressure, to study if there are differences among candidates with different genders. Therefore, we elaborated 3 hypotheses:

(h1) The plantar pressure of a shod foot is smaller than the one of unshod foot.

(h2) The plantar pressure increases once the speed of the gait increases.

(h3) The plantar pressure of a male feet is different than the one of a female foot.

Even if study of plantar pressure is widely used to detect diseases involving the foot(diabetes mellitus, rheumatoid arthritis, foot and toe deformities, change of foot load in sport)[8], this was not the purpose of this study because such a study demands more resources and larger team.

In the study took part the members of the team (3 members, 2 male and 1 female), an information about them and the measurement has been presented in the previous parts.

Even though, there is a difference between the plantar pressure with shoes and without shoes, there are limitations, for example, each participant had its own shoes which were different from the once of one another(size, material, sole thickness).

After all the measurements were done and the data was treated and analyzed accordingly, the first hypothesis was confirmed.

When wearing shoes, the maximal force, and maximal peak pressures, comparing to our expectancy, were lower. But a greater force was observed in the medial forefoot, and the peak pressures was without changes. Moreover, with or without shoes, a difference in the center of force, that passes towards the forefoot close to the designated area of the medial forefoot, was not observed. Better and softer cushioning of the above-mentioned area in the daily shoes could reduce the peak and the force pressures at this site. The same results were described by the M. Nyska [5].

Other phenomena that could be observed was that with the growth of the speed, the time needed to complete roll-over process increased. Also, when participants were wearing shoes, a smaller force influenced on the sole, a smaller contact area was needed, and the hallux contact was shorter.

According to (Jorgensen and Bojsen-Moller 1989), a greater weight of the participant will result in a larger contact area and the time needed to complete a roll-over increases. The results of this study are like (Jorgensen and Bojsen-Moller 1989). [9]

The second hypothesis was also confirmed. It means that once the movement is faster, implying a higher demand, the plantar pressure is higher. Also, it is very important to take into account the surface as a more rigid surface may result in a slower speed.

Furthermore, one more factor that must be considered when analyzing the effects of surface on tibial acceleration is the running velocity. A recent study [10] measured tibial acceleration on concrete and synthetic sports surfaces at the time of subjects running at 3.3 and 5.0 m/s. It was discovered that the tibial shock is considerably greater on asphalt than synthetic sports surfaces when running at 5.0 m/s. However, differences were not observed between surfaces when running at 3.3 m/s. In the current study, the speed was not measured, but on average, it was similar among the participants and no difference in tibial acceleration was found. But the above study and its confirmed hypothesis, confirm our hypothesis too. [10]

The third hypothesis was partially supported. For example, the male subjects in Sims et al. [11] demonstrated a significant increase in maximum force in the lateral forefoot when compared to women during a cross-over cutting task. In current study, a small difference could be observed between the same activity performed by the male participants and the female participants. Therefore, it seems that during both activities (cutting and running), males demonstrate a significant increase in plantar loading beneath the lateral forefoot. The differences with the literature for maximum force and contact area are related to the result of differences in the task being performed (cutting vs. running and in our case – running and walking). It can be considered a reasonable assumption given that significant differences exist in contact area, peak pressure and maximum force between different movement tasks [12] via this supporting our second hypothesis.

Moreover, a common small asymmetry between the plantar pressure of the left feet and the right one was observed during all types of movements and without regard to the gender.

5. Conclusion

In conclusion, this study supports that the plantar pressure is higher while walking without shoes, arriving to the same conclusion as the analyzed studies during the elaboration of this work. It is also in agreement with the other studies regardless the increasement of the plantar pressure with the increasement of the velocity. Knowing what type of shoes is better or what is the optimal velocity of gait can improve the future life quality of the human being, decreasing the probability of injuries. It is important to recognize that this study had several limitation, so in the future would be interesting to do the same experiment that was done, but with more participants and better conditions. Furthermore, it would also be interesting to study how the different plantar pressure patterns affect other parts of the body, mainly if studied for a long period of time.

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