Data Acquisition and Analysis in Biomechanics, Ergonomics and Sport

The effect of shoes and speed on vertical ground reaction force during walking

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ABSTRACT

Injuries are the fear of many athletes, in order to avoid them it is important to know and understand the mechanics of the human body. This study intends to investigate the effect of both shoes and speed on human gait, and see if they can be stress-relievers, or on the opposite if they can increase the risk of injury. This study is led on 3 participants, of different genders and different sports background. Our investigation showed that running put significantly more stress on the human body than walking (about 1,8 times more). Although this force is more important, it is also applied during a shorter time. Finally, wearing shoes resulted in a lower loading rate than being barefoot.

1. Introduction

Long distance walking, running, and hiking are one of the most preferred ways of physical activity. It is very important to analyze these processes as it is a very important part of human life and, if it is not done properly or in a correct manner, may cause injuries. According to Donald L. Goss (2015) there is a correlation between the above mentioned types of physical activities techniques and these injuries. Every step that is made must be performed in the best possible way, using the whole anatomy of the foot without having any part overused or underused. In addition, a well-developed technique of walking may improve the overall result, the feeling after walking, the runner distance and speed, as is it stated by Kyröläinen (2001). To analyze these processes, specific equipment is needed. Therefore, this type of analysis is done in laboratories using three-dimensional optical motion capture system and force plate.

The purpose of this research was to measure and analyze the Vertical Ground Reaction Force (VGRF) between walking, running activity and shoes' impact on each activity. Resulting from this analysis will be the impact characteristics, such as Ground Contact Time (GCT), Impact Peak (IP), Time to Impact Peak (TIP) or Loading Rate (LR).

Scientists such as J. Hamill (2010) put in evidence that there was noticeable differences between walking barefoot or shod, especially in the footfall pattern. J. Sinclair (2011) got to similar results, proving that running barefoot changed the impact characteristics in a way that could result in more injuries than running shod. Also, Nilsson and Thorstensson (1989) concluded that walking and running presented fundamental differences, and that running globally resulted in stress twice more important than walking.

2. Methods

2.1. Material

The material that was used consists in a force plate (Figure 1) placed in a wooden runway (Figure 2). The runway will allow the study subject to reach constant speeds, as it is wanted to measure a speed without any acceleration. It also allows to have a flat surface to walk or run on. The force plate can measure up to 2 axis in the meantime (the vertical and one horizontal, usually the axis the subject is walking on), but in this work only the vertical ground reaction force (VGRF) will be studied.

Figure 1. The PASCO PS-2124 force plate seen from underneath with its components made visible. This plate works with deformation sensors. The blue one measures the horizontal ground reaction force while the red ones measure the vertical ground reaction force. As there are only two sets of sensors, this force plate can only measure up to two axes in the meantime, but this is enough for the application.

2.2. Protocol

The measurement protocol is simple but needs to be done as precisely as possible. Two different speeds will be measured (running and walking), with and without shoes, which means 4 different sets of measures. The study was led on 3 different subjects, all having different height, weight, and sports background.

Table 1. Participants' characteristics

	Gender	Height (m)	Weight (kg)
Participant 1	Male	1,81	44
Participant 2	Female	1,65	38
Participant 3	Male	1,80	43

The test subject will have to step on force plate at a precise speed, and always with the same foot. Also, the foot needs to fit in the force plate so that all the information is collected. The first step is to put the sensor plate in the wooden runway and use the tare button to make sure the runway will not influence the results. Once this is done, the actual measuring can begin. One person was responsible for the measurement, and another was making sure the measure was done correctly (right foot, in the right place and with the right speed).

For each subject 10 walks with shoes, 10 without, 5 runs with shoes, 5 without have been recorded, which makes a total of 30 measures per person and a sum of 90 tests to analyze. Each of the sets of measures must be done at the same speed (the margin of error allowed was 0.15s for a length of 4.15m, which means a maximum error of ±3%). A simple smartphone was used for time measurement, as a precision of 1 millimeter was enough. It is necessary to notice that the first objective was to get 10 measures for each test and every person, which means a total of 120 measurements; however, it was not possible due to a lack of time. In the end 20 walks and 10 runs for each test subject have been recorded.

Figure 2. The wooden runway that was used for the measurements, it is 4,15m long. The circled part is where force plate is located. It is also covered by a wooden plate in order to get a surface as flat as possible.

2.3. Data analysis

In order to confirm or infirm hypothesis that have been set, collected data had to be analyzed to get insights out of it and to support the hypothesis.

Data was analyzed using MATLAB software. In order to get insights from it, it was needed to perform several operations. The first step was to import the data correctly such that it was possible to operate with it. After data was imported correctly it was needed to select just the useful data, for this step it was needed to analyze all cases and check if there are outliers that could perturb the data processing. Later, when every dataset was analyzed it was needed find out the position of the impact peak, the time needed until the impact peak was reached, the loading rate, ground contact time.

3. Results

After all data was collected and all calculus were done, the data had to be aggregated and presented in a concise and understandable table (Table 2).

Table 2. Aggregated analysed data

		Walking with shoes		Walking without shoes		Running with shoes		Running without shoes	
		Mean	StD	Mean	StD	Mean	StD	Mean	StD
Participant 1	GCT	0,63410	0,02209	0,61710	0,01536	0,25780	0,01013	0,26720	0,01819
	IP	1,12216	0,05517	1,10891	0,02122	2,23258	0,10244	2,19332	0,06423
	TIP	0,12450	0,01428	0,13240	0,02057	0,06540	0,02281	0,09560	0,00885
	LR	0,91763	0,16108	0,85678	0,13925	3,78310	1,42835	2,31370	0,26287
	Velocity	1,25924	0,02690	1,30209	0,02194	2,17897	0,06715	2,15961	0,03278
Participant 2	GCT	0,67230	0,02264	0,65978	0,02353	0,28380	0,01126	0,30800	0,01940
	IP	0,99440	0,06404	0,97609	0,04168	2,30147	0,09296	2,26574	0,06106
	TIP	0,49189	0,02060	0,50770	0,02112	0,12700	0,00418	0,12000	0,00515
	LR	0,23727	0,00850	0,22610	0,01137	1,81510	0,12289	1,89094	0,09572
	Velocity	1,14540	0,01775	1,12917	0,01541	2,10751	0,00928	1,96468	0,45625
Participant 3	GCT	0,68780	0,02237	0,66570	0,01546	0,31840	0,02355	0,37580	0,02355
	IP	1,05768	0,03977	1,08980	0,01847	1,85716	0,09031	1,52973	0,06555
	TIP	0,17100	0,01128	0,27880	0,18634	0,14380	0,00460	0,15940	0,04383
	LR	0,63984	0,04401	0,58838	0,36356	1,29373	0,09835	1,06064	0,46416
	Velocity	1,25059	0,04235	1,19148	0,03591	2,15742	0,11738	1,90907	0,40215

As it can be seen in the *Table 2*, the average velocity of the participants for walking was ±1,20 m/s with a standard deviation of 0,02 m/s; and for the running process , the mean velocity was ±2.07 m/s with a standard deviation of ±0,22 m/s.

In the following graph, the impact peak of all participants during all 4 processes is represented.

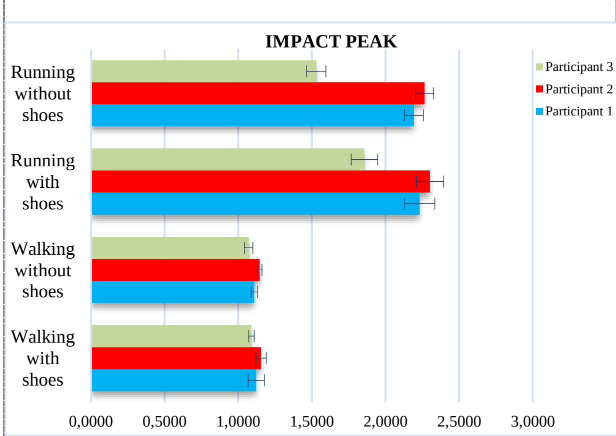

Figure 3. Graphical representation of the impact peak and standard deviation for all participants in all phases.

On average, the impact peak for walking processes was about 1,05 with a standard deviation of 0,03. For the running with shoes process, the impact peak was 2,13 with a deviation of 0,09, whereas for the running without shoes process, the impact peak was 1, 99 with a deviation of 0,06. Regarding the time to impact peak, it is possible to affirm that when a person is running with shoes, the time to the impact peak is shorter and the impact peak is higher, comparing with the time to impact peak of the other gait processes.

Comparing the results of the participants, during the walking activities, all of them had ± the same performance, whereas during the running processes it was possible to underly some differences: participant nr 2 has the highest impact peak among the other 2 participants. For participant number 2 and 3, the impact peak is almost double during the running comparing with walking, whereas for the participant number one, this difference is not that pronounced, even the

differences between the impact peak of the participants are not so considerable.

Another pattern that can be underlined from the impact peak graph is that the impact peak during the running with shoes is slightly higher than during the running without shoes process. Regarding the

For the second and third participants, the impact peak was smaller than the active peak, it means that among these two participants running and walking processes the fore-foot strike is more pronounced than the rear-foot strike, which could be observed in the first participant's movements.

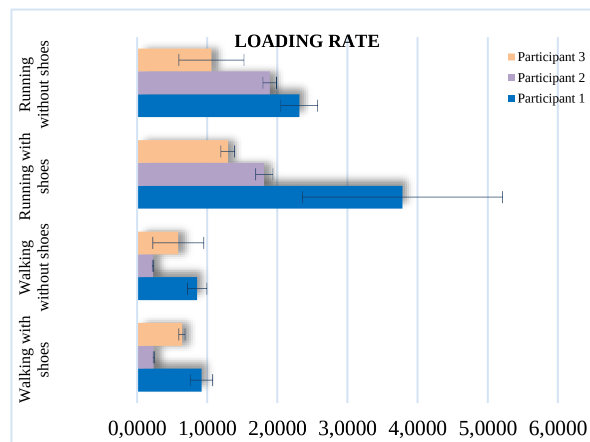

Figure 4. Graphical representation of the loading rate and standard deviation for all participants in all phases.

It is very important to control the loading rate during the daily walking/running processes. Therefore, in the above graph, the loading rate was represented. It is tended to say that as less is the loading rate as better it is. In the above graph it is easily visible that the loading rate vary in dependence of the type of the move. The participant 1 has the highest loading rate(during the running with shoes process) and the biggest standard deviation of the loading rate, its loading rate is much higher than the ones of the other participants which may suggest that there is an anomality in his/her running process. The same anomality can be underlined in the other processes, meaning that the participant one has a consistently higher loading rate which may cause insole injuries.

During the walking processes, the second participant has the smallest loading rate, which means that he/she performs the best among the other 2 participants.

In the meantime, during the running processes, the third participant is performing much better than the other 2, having the smallest loading rate.

4. Discussion

The studied hypothesis was that both, wearing shoes and type of gait would change the impact characteristics.

Obviously, this study had some limitations: each participant had different type of shoes and different sports backgrounds, the velocities for the same gait type with and without shoes are not the same, and the experiment conditions were not perfect.

It was shown that the ground contact time (GCT) decreased a lot from walking to running (0.6 – 0.7s for walking and 0.2 – 0.4s for running), which was expected since running tend to be faster than walking (Gallian, 2010, pp.315–316). However, regarding the influence of shoes our hypothesis was not validated, the difference on GCT is minimal when shod or barefoot, for both walking and running (0.01s and 0.03s, respectively) and these variations can regard the velocity variation. Previous studies are not in agreement with the current result, Roca-Dols et al. (2018) obtained lower GCT when running or walking barefoot. The difference can be in the type of shoes, since in Roca-Dols et al. cushioning running shoes were used.

According to Nilsson and Thorstensson (1989) the impact peak (IP) should increase with the velocity, therefore, the IP while walking should be lower than while running and this is in accordance with the current study. The results show that IP while walking is $(1.12\pm0.04)\times$bodyweight or $(1.11\pm0.02)\times$ bodyweight, when shod and barefoot respectively, and while running it is $(2.13\pm0.09)\times$bodyweight when shod and $(2.00\pm0.06)\times$bodyweight when barefoot. IP does not appear to be influenced by the use or not of shoes. The difference on the IP while running can once more be explained by the velocity, since the mean velocity is slightly different in both cases. Note that in different studies the influence of shoes on IP provided different results. Hamill et al. (2011) found significantly lower IP when the subject was barefoot, however, Sinclair et al. (2013) conclude that conventional shoes were associated with lower impact parameters. These opposite results may relate to the foot-strike pattern (that was not monitored in the current study) or with the study subjects' different sports background.

According to Chi and Schmitt (2005) the time to impact peak (TIP) is slightly lower while running than while walking, in the current study the same results were obtained, while walking the mean TIP was 0.26 ± 0.02 s and 0.31 ± 0.08 s (respectively for shod and barefoot cases) and while running it was 0.11 ± 0.01 s and 0.12 ± 0.01 s (by the same order). However, these results are not in agreement with Blackmore, Ball and Scurr (2011), in that study the TIP does not vary with the gait type. Regarding the influence of wearing shoes in this parameter, Hamill et al. (2011) have reported a considerably lower TIP when barefoot. Although, according to the current results the TIP is practically the same in both conditions (the difference between walking barefoot and shod will not be considered, as this stems from the fact that the TIP of participant 2 when barefoot is quite high. However, this value for this same participant also has a high standard deviation).

Finally, regarding the loading rate (LR) the study hypothesis is fully supported. The LR while running is considerably higher than while walking (either with or without shoes), these results are supported by previous studies. Per example, Blackmore, Ball and Scurr (2011) also concluded that, when barefoot or wearing socks, the LR is significantly higher while running. Also, the results about the influence of shoes are supported by previous articles. Hamill et al. (2011) showed that running barefoot would lead to a lower LR than running with shoes, in the current study the same conclusion was taken, the LR is lower when barefoot, for both walking and run, however this difference is more pronounced while running,

The initial hypothesis was not completely supported by the data, however it was partially supported and to be sure about the points that were not validated further studies with more participants and better conditions would be necessary, namely with a velocity control system more accurate and with participants in equal conditions.

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