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COMPARISON OF VERTICAL GRF OBTAINED FROM FORCE PLATE, PRESSURE PLATE AND INSOLE PRESSURE SYSTEM

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The aim of this study is to compare the vertical component of the ground reaction force (GRF) obtained from the force plate (FP) with those obtained from pressure plate (PP) and insole pressure system (IPS), and to compare the values found between the two pressure systems (PP vs IPS).Twelve subjects walked at a self-selected speed on a 6m walkway, where in the middle there was the FP, and over it, the PP. Simultaneously, the participants used the IPS. The results suggest that there are larger differences between the force values measured by the baropodometric systems when compared to FP, where the baropodometric systems seem to underestimate the force values. Therefore the absolute values recorded by the baropodometric systems should be interpreted very carefully and the comparison of results acquired by different systems should be avoided.

KEY WORDS: plantar pressure, plantar force, kinetic analysis, baropodometry, accuracy.

INTRODUCTION: During gait, loads are transferred between the human body and the ground, starting at the calcaneous and finishing in the forefoot, until toe off (Burnfield et al., 2004). The measurement of this contact forces offers a variety of information about the external loads to which the body is submitted in different situations. The kinetic analysis of human gait comprehend the measurements of forces and pressures (Rosenbaum & Becker, 1997) being the baropodometry by means of a pressure plate (PP) or insoles pressure system (IPS) and extensiometry by means of a force plate (FP) the most used methods .
The pressure is calculated using the vertical component of the ground reaction force (GRF), and in this way the pressure sensors are, essentially, force transducers that measure the force acting in a surface of a known area (Cavanagh & Ulbrecht, 1994).
The accuracy and repeatability of the absolute values obtained by means of baropodometry have been questioned (Nicolopoulos et al., 2000; Rosenbaum & Becker, 1997; Woodburn & Helliwell, 1996). In other way, the FP provides the most accurate dynamic force measurements (Cobb & Claremont, 1995). Considering this, the purpose of this study is to compare the vertical component of the GRF obtained from the FP with those obtained from PP and IPS, and to compare the values found between the two pressure systems (PP vs IPS).

METHODS: Participants: Twelve subjects participated in this study (7 women and 5 men) with ages between 25 and 35 years old and the body weight between 54 and 81 kg, physically active, without any pain or limitation during gait.
Instruments: A Footscan PP (RsScan, Olen, Belgium) with 0.5 m length and 4096 sensors, where each sensor presents an area of 0.375 cm², making a spatial resolution of 2.7 sensor/cm², operating at a sample frequency of 300Hz; a Pedar IPS (Novel, Munich, Germany) with 99 sensors per insole operating at a sample frequency of 100Hz; and a Bertec FP (model 4060-15, Bertec Corporation, Columbus, USA) operating at a sample frequency of 1000Hz were used. All equipments were calibrated within a period of one year before testing.
Experimental Protocol: The participants walked at a self-selected speed in a 6 m walkway, where in the middle there was the FP, and over it, the PP. At the same time, the subjects used the IPS. Therefore, the data from the three systems were recorded simultaneously. The participants should step over the PP with the right foot and the tests were considered valid only when the entire foot was in contact with the plate. Three valid tests for each subject were performed.

Data analysis: For the PP data acquisition was used the Gait Module 2nd Generation software (RsScan, Olen, Belgium); for the IPS the software Pedar-x Data Acquisition (Novel, Munich, Germany); and for the FP the software Acqknowledge (BIOPAC System, California, USA). The pressure data (pressure values of each sensor in each frame) and the force data (Fz in each time instant) were exported and, using the software MATLAB 7.0 (MathWorks, Massachusetts, USA) a program was developed to obtain the force peak values of both pressure systems and FP.
Statistical Analysis: For the comparison of the results between instruments, the protocol proposed by Bland and Altman (1986) was used, where the mean differences between instruments and the confidence interval of the differences were analyzed.

RESULTS: The figures represent the dispersion of the differences and the mean of the differences of the following comparisons: FP vs IPS (Fig. 1), FP vs PP (Fig. 2) and PP vs IPS (Fig. 3). The confidence intervals of the differences between FP vs IPS, FP vs PP and PP vs IPS were, respectively, 40.1 to 510.3 N, 252.4 to 669.7 N and -498.1 to 208.6 N.

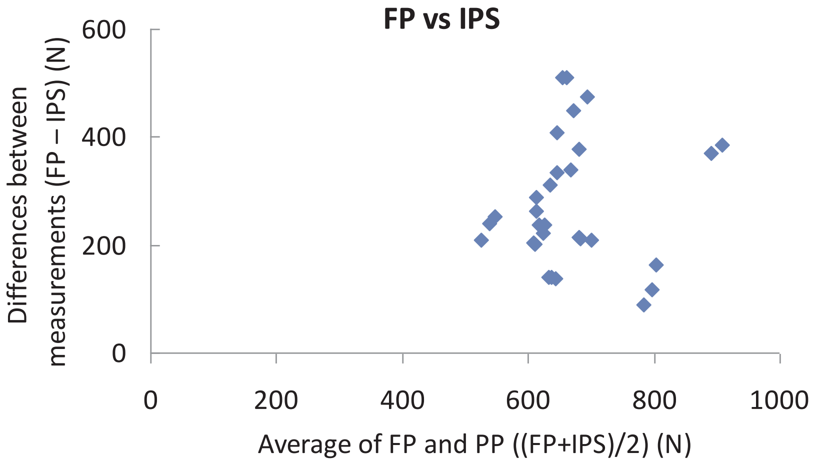

Figure 1: Differences between Force Plate (FP) and Insole Pressure System (IPS).

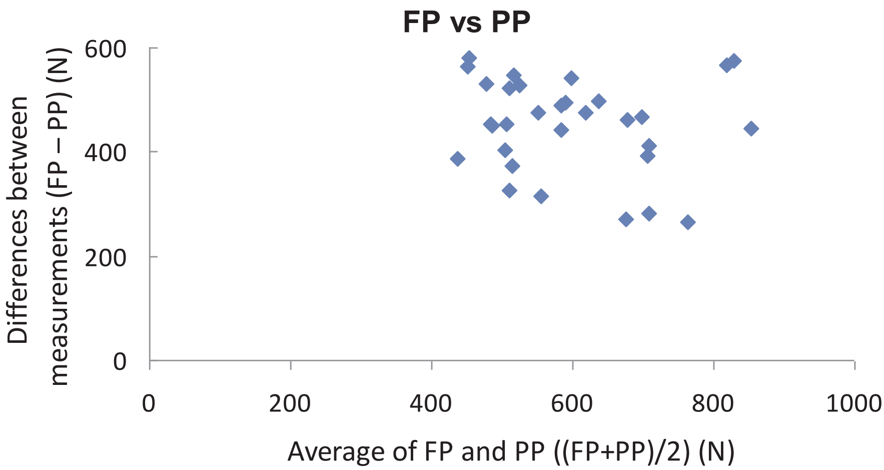

Figure 2: Differences between Force Plate (FP) and Pressure Plate (PP).

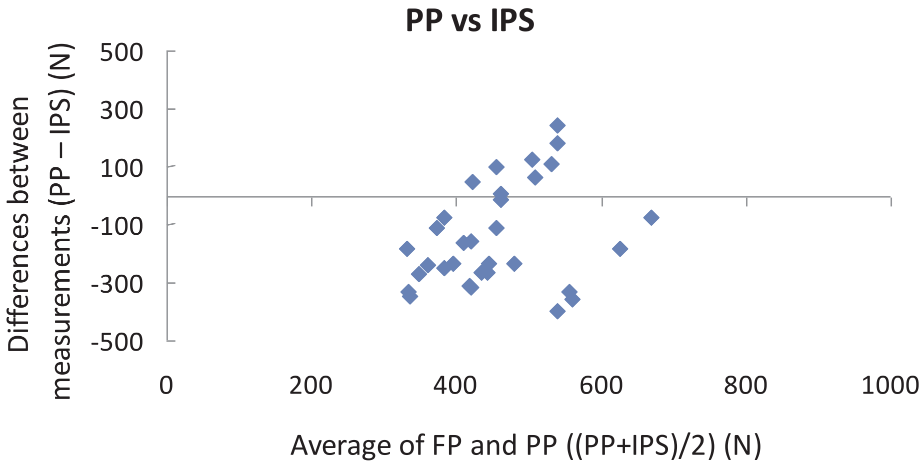

Figure 3: Differences between Pressure Plate (PP) and Insole Pressure System (IPS).

DISCUSSION: The results presented in this study indicate a large difference between the absolute force values recorded by the FP, which is considered the "golden standard" for such measurements (Cobb & Claremont, 1995), when compared to the pressure systems (PP and IPS), where the forces seem to be underestimated in the baropodometric systems. Besides, when the baropodometric systems were compared with each other, larger differences were also found, but not so pronounced as when compared to FP. Even if the values were normalized by the body weight of the subjects the differences probably are very similar, since the body weight of the participants is the same for all instruments.
A possible explanation for such findings would be the fact that IPS measures the force for each sensor, which is not necessarily the same as the vertical GRF since the angle of the foot influences the angle of the force vector (Barnett et al., 2000). As a result, the force vectors measured by the IPS are different from the vertical force measured by the FP. As the plates were placed one over the other, they should suffer the contact at the same angle of the foot; therefore, probably this would not be the real factor responsible for the discrepancy of the data. Another possible explanation for this underestimation that the baropodometric system presents would be because of a pressure threshold where force and pressure data under this threshold are not recorded (Barnett et al., 2000); this threshold would be used clinically to reduce the noise during the data collection. Even though, during gait cycle, part of the loads on the plantar surface would be under this threshold explaining the constantly lower force values in the baropodometry when compared to FP.
Other studies reported that the baropodometric systems have a good capacity of providing relative values about the distribution of the force/pressure on the plantar surface, but the absolute values should be analyzed carefully (Nicolopoulos et al., 2000; Woodburn & Helliwell, 1996). Considering the comparison of baropodometric systems, a possible imprecision of the insole sensor, generated by changes in temperature inside the shoe is also named as a factor that could promote changes in measurements (Cavanagh & Ulbrecht, 1994). However Low and Dixon (2010), even controlling this factor before their data collection, they found the same differences described in the literature.

CONCLUSION:
The results presented suggest that there are larger differences between the force values measured by the baropodometric systems when compared to FP, where the baropodometric systems seem to have an underestimation of the force values. Therefore, absolute values

recorded by the baropodometric systems should be interpreted very carefully and, if possible, to associate these systems with FP, creating correcting factors which could increase the consistency of these data. Considering the PP and IPS, the analysis of the distribution of the pressure (only relative values) seems more appropriate and the comparison of data collected by different instruments should be avoieded. However, we suggest replicating this study with a larger sample size and number of steps to increase the consistency of the results.

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