Pilot study: Assessing repeatability of the EcoWalk platform resistive pressure sensors to measure plantar pressure during barefoot standing

Martha Zequera, Oscar Perdomo, Carlos Wilches and Pedro Vizcaya
Pontificia Universidad Javeriana, Department of Electronics, BASPI Research Group - Diabetic Foot, Carrera 7 No. 40 - 62, Bogotá, Colombia
E-mail: mzequera@javeriana.edu.co

Abstract.
Plantar pressure provides useful information to assess the foot’s condition. These systems have emerged as popular tools in clinical environment. These systems present errors and no compensation information is presented by the manufacturer, leading to uncertainty in the measurements. Ten healthy subjects, 5 females and 5 males, were recruited. Lateral load distribution, antero-posterior load distribution, average pressure, contact area, and force were recorded. The aims of this study were to assess repeatability of the EcoWalk system and identify the range of pressure values observed in the normal foot. The coefficient of repeatability was less than 4% for all parameters considered.

1. Introduction
The foot is one of the most unique and complex biomechanical structures in the nature [1]. Plantar pressure measurements provide useful information to know the normal condition or disorders of the feet [2]. Several studies were performed on healthy subjects, looking for repeatability, parameters and mathematical relationship between subjects depending age, size, weight, height and BMI [3, 4, 5, 6]. The plantar pressure measurement systems have emerged as popular tools in clinical, ergonomics, and academic research environments.

Unfortunately, the commercially available measurement systems have objectionably sensitive to several disturbances, but this aspect is not reported factually in the literature. Some metrological performances of plantar pressure measurement systems showed the presence of bias and random errors without calibration information or schemes for error compensation by the manufacturer, which leads to uncertainties in the measurements, carried with these plantar pressure measurement systems [7].

EcoWalk system is a relatively new product among the platform pressure measuring devices. Repeatability is one of the elements which may define such dependability [8]. Clinical personal need good repeatability to ensure the best diagnose based their judgments on consistent measures [9]. Therefore, the difference ranges between of normal in-shoe pressure values in a healthy and unhealthy people are needed to identify abnormalities.

The aims of this study are to assess the repeatability of the EcoWalk system and identify the range of pressure values observed in the normal foot.
2. Materials and methods

2.1. Subjects

Ten healthy volunteers were chosen for this study, 5 women and 5 men, aged 18 - 27 years and body mass index below 30. Subjects were excluded if they presented musculoskeletal injuries or biomechanical alterations, which may affect measurements. Ethical approval was granted by the Ethics Committee for Medical Research of the San Ignacio Hospital. All subjects participating in the study signed a written informed consent.

2.2. Equipment

The measurement system consisted on 3 components: the pressure platform EcoWalk (Ecosanit, Anghiari, Arezzo, Italy), the software EcoFoot 4.0, a support, a digital weight scale, and a reference frame.

The pressure platform EcoWalk is composed by 2304 resistive sensors, arranged in an array of \(48 \times 48\) sensors (1 sensor/cm\(^2\)), and a sample rate of 30 Hz. EcoFoot 4.0 was used to measure: lateral load distribution (LLD), antero-posterior load distribution (APLD), average pressure (AP), contact area (PA), and force (F).

The support was given to help the subjects to keep their balance during the measurement, but without affecting seriously the pressure measured. The purpose of the reference frame is to maintain the feet in an anatomical position during measurements. Previous studies revealed that a reference frame allows greater repeatability of pressure measurements [10].

2.3. Protocol

For recruitment, a doctor performed a comprehensive physical exam of the participants, assessing the state of their feet, and selecting those who didn’t present musculoskeletal injuries or biomechanical alterations. The subjects approved were asked to be barefoot, with their pockets empty, jewelry and watches removed, and wearing comfortable clothes, in order to avoid changes in the measurement.

Each subject were measured 30 times with a technique for controlling the position of their feet, using the reference frame. The technique consisted on position the feet using the frame, and removing it before measuring the plantar pressure, to avoid noise caused by the presence of the frame on the platform.

The measurement process was supervised by the research group staff, who guided the accommodation of the feet of the subject and body position.

2.4. Data measured

The pressure platform EcoWalk measures plantar pressure distribution, capturing the pressure at each sensor and calculating the different variables. LLD indicates the percentage of load on each foot; APLD is percentage of load in rearfoot and forefoot; AP is the average pressure on each foot; CA are the count of all sensors activated on each foot, since the sensor area is 1cm\(^2\); and FI is the force calculated from the sum of pressures on each sensor on each foot (1):

\[
F = \sum P_{\text{sensor}} \cdot CA
\]  

(1)

2.5. Data processing

After measuring the 10 subjects, each measurement (300 measurements in total) were processed to calculate CA and F, while LLD, APLD, AP were given by the software. On each variable, an statistical analysis was carried out in order to assess its performance and the least variability within-subjects, was selected.

The variable selected was analyzed in order to select the most significant measurements from each subject.
2.6. Statistical analysis
An ANOVA statistical analysis was performed using the software SPSS, mean, median, mode, variance and standard deviation, with independent variables being gender, foot, and position (anterior or posterior).

3. Results
The set of signals obtained during the study in ten healthy subjects were analyzed using parametric statistical and nonparametric methods with MATLAB software. A significant difference was found within-subject comparison between different parameters under study.

The statistical analysis showed a significant response between subjects with different gender and type of foot analyzed, which is an expected response according to the literature.

In Figure 1 is shown the force variable in the ten subjects studied, the values presented an abnormal distribution in within-subject and between-subject. A larger variance and a tendency to a non-normal data, it can be modeling and represented such as a skewed distribution.

![Figure 1. Subjects vs Force](image)

In Figure 2 is shown the contact area variable in the ten subjects. It was observed that there is less variance, which leads to a more consistent data within a smaller range. Statistical tests showed that the distribution was normal because the mean, median and mode were approximately equal.

4. Discussion
The repeatability of the EcoWalk system was assessed in ten healthy subjects. It was identified the range of pressure values and contact area for different age, size, weight, height and BMI. The coefficient of repeatability (CR) for the contact area parameter was less than 4% for all the ten subjects.

According to [3, 4, 5], the repeatability can be estimated through mathematical and statistical analysis of the parameters involved in the measurements of the pressure plantar system. The contact area can be an excellent parameter for helping objectively to choose the most representative sample in a set of measurements.
The needs of a metrological performance of the available measurement systems by manufactures have to be reported. The presence of bias and random errors with an appropriated calibration information or schemes for error compensation lead to a totally knowledge of the uncertainty allowing accuracy in the measurements.

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