REVISTA BRASILEIRA DE REUMATOLOGIA

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SOCIEDADE BRASILEIRA DE REUMATOLOGIA

Original article

Variability and repeatability analysis of plantar pressure during gait in older people

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ARTICLE INFO

Article history:
Received 12 August 2014
Accepted 17 March 2015
Available online 9 August 2015

Keywords:
Gait
Kinetics
Aging
Biomechanics
Foot

ABSTRACT

Introduction: Repeatability and variability of the plantar pressure during walking are important components in the clinical assessment of the elderly. However, there is a lack of information on the uniformity of plantar pressure patterns in the elderly.
Objective: To analyze the repeatability and variability in plantar pressure considering mean, peak and asymmetries during aged gait.
Methods: Plantar pressure was monitored in four different days for ten elderly subjects (5 female), with mean ± standard-deviation age of 73 ± 6 years, walking barefoot at preferred speed. Data were compared between steps for each day and between different days.
Results: Mean and peak plantar pressure values were similar between the different days of evaluation. Asymmetry indexes were similar between the different days evaluated.
Conclusion: Plantar pressure presented a consistent pattern in the elderly. However, the asymmetry indexes observed suggest that the elderly are exposed to repetitive asymmetric loading during locomotion. Such result requires further investigation, especially concerning the role of these asymmetries for development of articular injuries.

Análise da variabilidade e repetibilidade da pressão plantar durante a marcha de idosos

Palavras-chave:
Marcha
Cinética
Envelhecimento
Biomecânica
Pé

RESUMO

Introdução: A repetibilidade e a variabilidade da pressão plantar em avaliações da marcha são componentes importantes na avaliação clínica do idoso. Contudo, pouco é conhecido sobre a consistência dos padrões de pressão plantar em idosos.
Objetivo: Analisar a variabilidade e repetibilidade da pressão plantar durante da marcha de idosos, considerando valores médios, picos e assimetrias.

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http://dx.doi.org/10.1016/j.rbre.2015.07.010

Métodos: A pressão plantar foi avaliada em quatro diferentes dias em dez idosos (5 mulheres), com idade média ± desvio-padrão de 73 ± 6 anos, durante o andar descalço em velocidade preferida. Os dados de pressão plantar foram comparados entre as pisadas em cada dia, e entre os diferentes dias de avaliação.

Resultados: Dados de pressão média e pico foram similares entre os diferentes dias de avaliação. Os índices de assimetria observados foram similares entre os diferentes dias avaliados.

Conclusão: A pressão plantar (média e pico) apresentou um padrão consistente nos idosos. Contudo, os índices de assimetria observados sugerem que idosos estejam sistematicamente expostos a cargas assimétricas durante a locomoção. Esta observação requer futuras investigações, especialmente em relação ao impacto destas assimetrias na origem de doenças articulares.

Introduction

Gait is vital for older people in order to maintain independence, as it allows carrying out daily activities and contributes to the functioning of various body systems. Since biped walking is a common ability to humans, it serves both as a means of locomotion as an exercise modality. During the gait, every contact of the feet to the ground generates an impact due to the action of the ground reaction forces.[1,2]

Based on force measurements and area of foot contact with the surface, it is possible to quantify the plantar pressure during walking. Thus, we can access important information for the investigation of the stress generated in the different regions of the plantar surface.[3] The published data suggests that older people experience higher plantar pressure on the regions of the 2nd, 3rd and 5th metatarsophalangeal joints and hallux when walking.[4] This increase of plantar load on soft tissues, which have stiffened due to the aging process, often progresses to metatarsalgia in the elderly.[5]

Additionally, excessive exposure to loads on the soft tissues of the feet may lead to problems commonly known as pressure ulcers.[6] These injuries can arise from repetitive microtrauma, causing a decrease in the elastic fibrous tissue water content and a gradual loss of collagen in the fat pad of the heel, contributing to the decrease in elasticity and the ability of fat pad to absorb impact.[7,8] The changes in mechanical properties of heel fat cushion also lead to impact-induced injuries, and to heel pain.[9] These conditions have been assumed to be similar between lower limbs. However, evidence suggests that functional lateralization is a dynamic component of human motor development, and can influence differences between the lower limbs during gait.[10]

In the context of human locomotion, the subject of our study, asymmetries can be seen as deviations on the similarity of performance among right and left hemibody. These deviations are considered significant, based on statistical tests or from the application of symmetry indexes.[11] Many studies have discussed the effects of asymmetries in locomotion parameters, suggesting that asymmetry may influence performance characteristics and also the risk of injury to the lower limbs.[11,12]

Chavet et al.[13] assessed asymmetries in a scenario of impact and shock transmission in lower limbs and suggested that the repetition of asymmetries can be more damaging than its own magnitude. That is, even low rates of asymmetry, if experienced in a repetitive manner, can be a risk factor for injuries.[13] In this sense, the asymmetry index quantification can provide important parameters for the evaluation of asymmetric loads in locomotion. Considering the above observations on the ability of impact absorption during gait in the elderly,[14] repeatability of asymmetries in the gait in this population can be a risk factor for the onset of foot injuries. The popularization of the use of baropodometry systems boosts the discussion of the clinical applications of plantar pressure measurement in the evaluation of human movement, especially in relation to variability and consistency of the measures.[15] Previous studies have suggested that a minimum of three measurements in each test would be necessary to obtain a good level of consistency in measures.[16,17]

However, little is known about the repeatability of plantar pressure parameters in the elderly. In addition, most clinical evaluations are carried out in only one day, not considering possible variations that may occur when more evaluations are performed. From the point of view of the asymmetries, the repetitive load can result in a greater risk than its own magnitude, and there are few studies that investigate these issues in the gait of the elderly. Thus, this study aimed to analyze repeated measures of plantar pressure during the gait of elderly people, in order to discuss the consistency of mean and peak pressure measurements, as well as the asymmetry indexes on different days.

Material and methods

Participants

Initially, a group of 50 senior citizens was invited to participate in the study. Many participants failed to attend the study visits. Since this is a study that involves repeated measurements, participants who were not assessed in the given period were excluded. After the evaluation period, 10 senior citizens were included in this study (5 men and 5 women). All were recruited from a local Community Center for the Elderly, where they took part in recreational activities, as a group, three times a week. All seniors deemed to be independent were invited to participate in the experiment and those who have completed the four evaluations in a maximum period of seven days were included in this study. Even those who did not complete the protocol in the defined period received detailed results of their assessments, which were explained by a physical therapist. Data were also provided for the Community Center, in order to be filed with documents and other clinical examinations of these elderly people. The number of subjects included in our study was similar to that in studies with a similar scope[18,19] and, as described below, it was noted that the participants had a fairly homogeneous performance.

To be included, participants had to be aged 60 years or older and be able to walk without assistive devices. They should attend at the assessment site in previously scheduled days and times. In the case of contact lenses user for visual correction, these devices should be used in the evaluation days. The elderly should not have skin lesions on their feet nor deformities that could influence plantar pressure. Exclusion criteria were: injury to any of the lower limbs in the last year, lower extremities claudication, musculoskeletal and/or neuromuscular diseases affecting independent walking. Before starting participation in the study, all seniors signed an informed consent form approved by the research ethics committee of the local university (Protocol 062 011).

Study design

Our research has a cross-sectional observational design, where the elderly were assessed when walking barefoot, as they walked in their preferred speed along a path of 9 m in a straight line. The evaluation was performed barefoot in order to minimize the influence of footwear on measures of interest in this study. The gait protocol was repeated in 4 non-consecutive days, in an interval of no more than seven days between assessments. For each evaluation day, the plantar pressure measurements were recorded for 10 footsteps with each foot. The plantar pressure information was recorded using an instrumented mat, positioned in the middle of the path. We have attempted to conduct the evaluation of the gait always at the same hour and time of the day, preferably between 09:00 and 12: 00 h. Data were compared between footsteps on each day, and between different days of assessment. The asymmetry index was also calculated for all footsteps and days of evaluation.

Plantar pressure assessment

A computerized baropodometer gait mat (Matscan, Tekscan Inc., USA) was used to record plantar pressure during each footstep. Data were recorded at a 400 Hz sampling rate. Plantar pressure measurements were performed to determine mean and peak pressures, considering the entire area of foot contact with the ground in 10 footsteps recorded for each foot in each day. From this information, asymmetry indexes between the legs were also quantified for mean and peak pressures, determined on the basis of the total area of foot contact with the ground.

For data acquisition, the instrumented mat was positioned in the middle of the 9-m path. Data were measured with a resolution of 1.4 sensors per square centimeter, totaling 2288 sensors. Footsteps with right and left foot were collected randomly, and the subjects were not asked to step with a certain foot on the mat. The subject did not know when an attempt was valid or not; he/she just was informed about the end of the experiment, when 10 footsteps for each foot had been recorded. From the information on plantar pressure, we calculated the mean and peak pressures for the entire area of each foot, in each footstep. Attempts were considered valid when the whole foot touched the baropodometer positioned on the ground.[18,19]

Mean speed evaluation

To measure the mean speed of each participant and thus to characterize the group of participants, the walking time was timed by the examiner using a digital timer (SW2018, CRONOBIO, Brazil). The mean speed was calculated from the information on distance covered and on time for each 9-m distance; subsequently, the means for each day were calculated.

Statistical analysis

Data of mean gait speed were grouped in mean and standard deviation, for comparison between the days. For plantar pressure data (mean and peak pressures), the information was arranged in mean and standard deviation format, considering the values of 10 footsteps each day, for each leg. Data were compared between footsteps at each day, and between different days of assessment. The coefficient of variation (CV) was calculated using standard deviation/mean ratio.

To verify the normality of data distribution, the Shapiro–Wilk test was used. The one-way ANOVA with *post hoc* Tukey test was used to compare variables among the four days, as well as to compare the footsteps each day for right and left legs. To express the magnitude of the asymmetries in each day, the asymmetry index (AI) was calculated, using Eq. (1).[10] The level of significance was set at 0.05 for all analyzes. Statistical analyses were performed using SPSS version 17.0.

$$AI\% = [(\text{right} - \text{left})/\text{right}] * 100 \quad (1)$$

Results

The clinical characteristics of the participants are presented in Table 1.

When plantar pressure data for each foot were compared between different days, we observed a consistent pattern in mean pressure, with no difference between days for both the right leg ($F_{(3)} = 0.728$; $p = 0.542$) and left leg ($F_{(3)} = 0.495$; $p = 0.688$). Similar results were observed for peak pressure for both the right leg ($F_{(3)} = 0.526$; $p = 0.667$) and left leg ($F_{(3)} = 0.033$; $p = 0.992$) (Fig. 1).

When the plantar pressure variability was compared between different days, we also observed a consistent pattern of variation in mean pressure over the four days, with no significant differences for both the right leg ($F_{(3)} = 1.245$; $p = 0.308$) and left leg ($F_{(3)} = 0.335$; $p = 0.800$). This pattern was

Table 1 – Clinical characteristics of the participants. Data presented as mean ± standard deviation. BMI, body mass index, calculated by dividing the body weight by the height squared.

Characteristics	Mean ± standard deviation
Age (years)	73.20 ± 6.09
Body weight (kg)	66.35 ± 13.03
Height (m)	1.62 ± 0.07
Mean speed (m/s)	0.88 ± 0.14
BMI (kg/m^2)	25.40 ± 4.58

also observed for the variability of the peak pressure for both the right leg ($F_{(3)} = 0.600$; $p = 0.619$), and left leg ($F_{(3)} = 0.415$; $p = 0.743$) (Fig. 1).

The mean ± standard deviation of the asymmetry index for mean plantar pressure on different days was 4.79% ± 0.99% and for peak pressure was 6.73% ± 1.36%. Both indexes were similar between the four evaluation days ($F_{(3)} = 0.986$, $p = 0.410$ and $F_{(3)} = 0.125$; $p = 0.944$ for mean and peak pressure, respectively).

By comparing the asymmetry index of mean and peak pressures, no significant differences were observed on the first ($t_{(9)} = -1.740$; $p = 0.116$), second ($t_{(9)} = -1.161$; $p = 0.275$), third ($t_{(9)} = -1.308$; $p = 0.223$), or fourth evaluation day ($t_{(9)} = -0.072$; $p = 0.944$) (Fig. 2).

When the mean pressure for the right and left leg (Fig. 3) was compared between 10 footsteps analyzed on each day, the results showed that on day 1, there was an effect of footsteps on mean pressure ($F_{(9)} = 11{,}092$; $p = <0.001$) where the *post hoc* test indicated difference between the 1st and 5th footstep ($p < 0.05$) and between the 1st and 8th footstep ($p < 0.05$).

In other footsteps and other days, we did not observe any difference between the footsteps of the right leg ($F_{(9)} = 0.405$, $p = 0.930$; $F_{(9)} = 0.795$, $p = 0.622$; $F_{(9)} = 0.477$; $p = 0.886$; for days 1, 2, 3 and 4, respectively) and left leg ($F_{(9)} = 0.302$, $p = 0.972$; $F_{(9)} = 0.312$, $p = 0.969$; $F_{(9)} = 0.446$; $p = 0.906$; $F_{(9)} = 0.288$, $p = 0.977$; for the days 1, 2, 3 and 4, respectively).

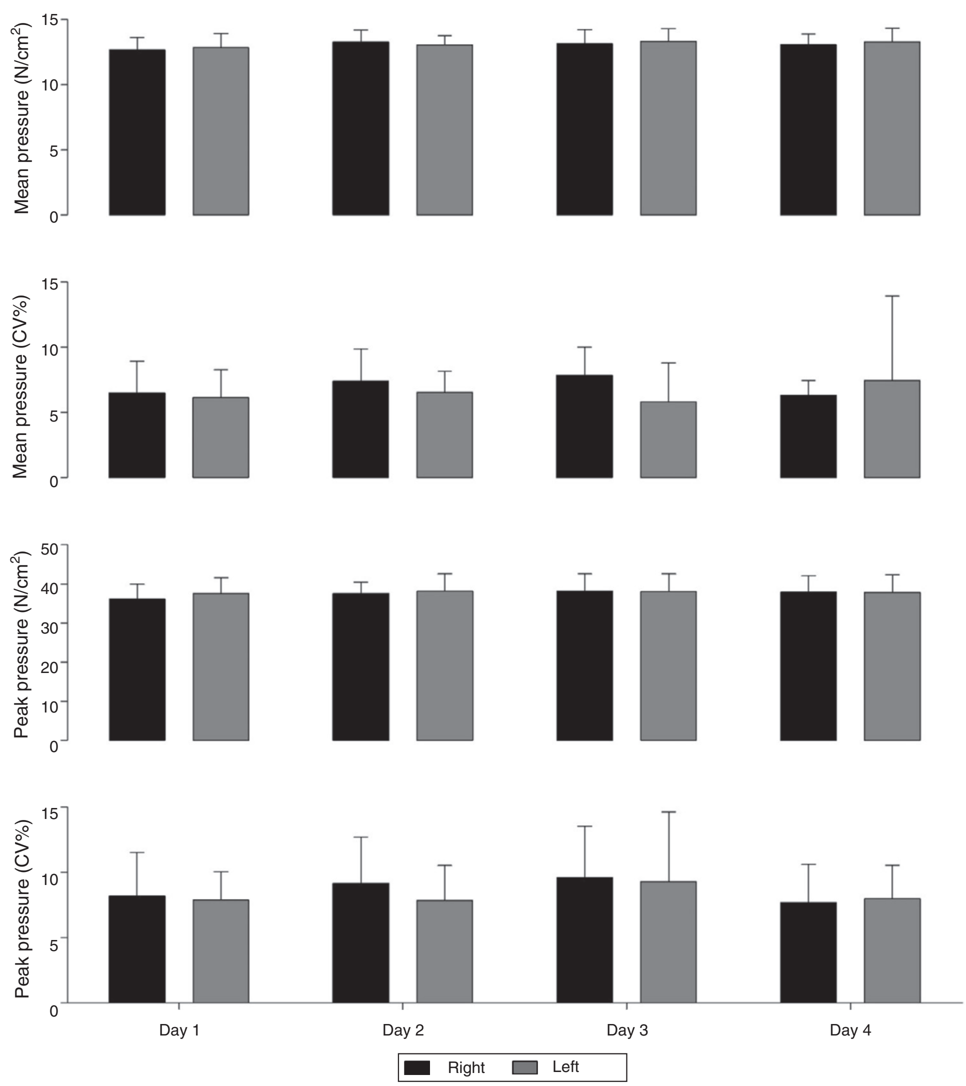

Fig. 1 – Comparison among days for mean and peak plantar pressures. Mean (columns) and standard deviation (vertical lines) for mean pressure (N/cm^2), mean pressure variability (CV%), peak pressure (N/cm^2) and peak pressure variability (CV%) from top to bottom of the figure, respectively.

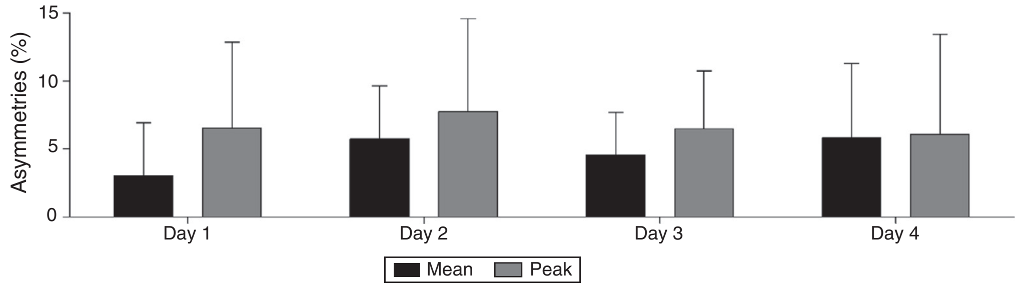

Fig. 2 – Comparison of asymmetry indexes for mean and peak plantar pressure among days. Mean (columns) and standard deviation (vertical lines) for the asymmetry index (%) in the four-day evaluation for mean pressure (black columns) and peak pressure (gray columns).

When the peak pressure for the right and left legs (Fig. 4) was compared among the 10 analyzed footsteps on each day, there was no difference between footsteps with the right leg ($F_{(9)} = 0.359$, $p = 0.951$; $F_{(9)} = 0.706$, $p = 0.702$; $F_{(9)} = 0.419$, $p = 0.922$; $F_{(9)} = 0.454$, $p = 0.901$; for the days 1, 2, 3 and 4, respectively) or with the left leg ($F_{(9)} = 0.359$, $p = 0.951$; $F_{(9)} = 0.196$, $p = 0.994$; $F_{(9)} = 0.380$, $p = 0.942$; $F_{(9)} = 0.189$, $p = 0.995$; for the days 1, 2, 3 and 4, respectively).

Discussion

In this study, we analyzed the variability and repeatability in mean plantar pressure, peak pressure, and asymmetries in the gait of the elderly. Our main results suggest that mean and peak pressures in the gait of the elderly were consistent between different days, reflecting similar asymmetry indexes across different assessments. This is an important result, for it suggests that the evaluated seniors experience different lower extremity foot loading patterns while walking. To date, ours appears to be the first study to describe this gait pattern in the elderly.

In the analysis of different footsteps on the same day, we found a consistent pattern of mean and peak pressures, that is, the plantar pressure values observed did not differ between footsteps and days, except for two isolated differences in mean pressure. This also contributed to the similarity between asymmetry indexes. This repeatability of asymmetries, even with low magnitudes, may result in cumulative loads during locomotion, reiterating what is described in the literature, namely, that the repetition of the asymmetric impact could result in greater risks than its own magnitude.[13] The human foot is responsible for cushioning and shock absorption during gait.[8] Thus, the repetition of asymmetric patterns during plantar pressure application may exert a peculiar effect in the elderly, because in this population the soft tissues of their feet exhibit less shock absorption capacity,[20] as well as a decreased propulsive ability during the gait cycle.[18,21]

Our experiment considered seniors who enjoy independence; this fact could have been decisive so that, even when aged 60 or older, a consistent gait pattern is observed among our participants. Our results might be different if a group of elderly with some limitation was considered, as healthy subjects are able to adapt their gait.[22] However, we must consider that our measurements were obtained from the total area of

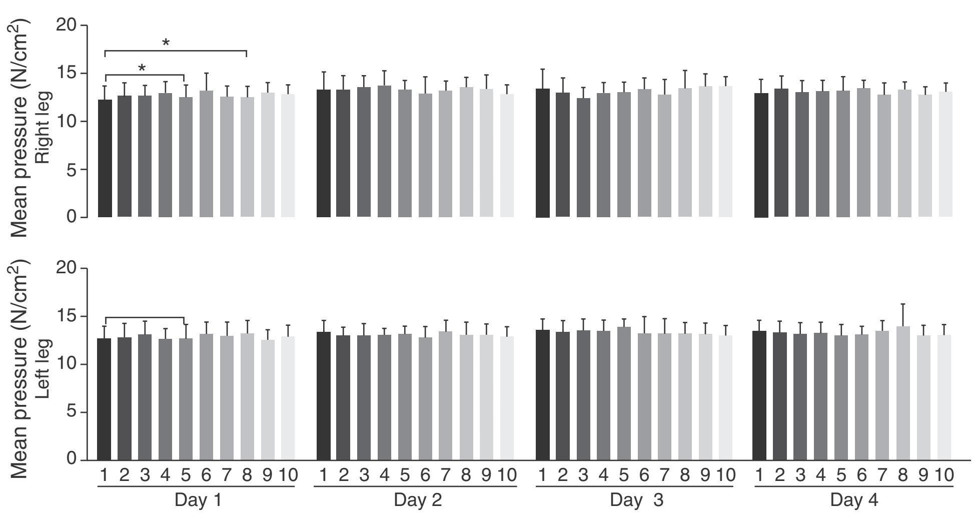

Fig. 3 – Comparison of mean plantar pressures between footsteps for each day. Mean (columns) and standard deviation (vertical lines) for mean pressure (N/cm²) considering 10 footsteps each day, for right (top line) and left (bottom line) leg. *Indicates difference between footsteps.

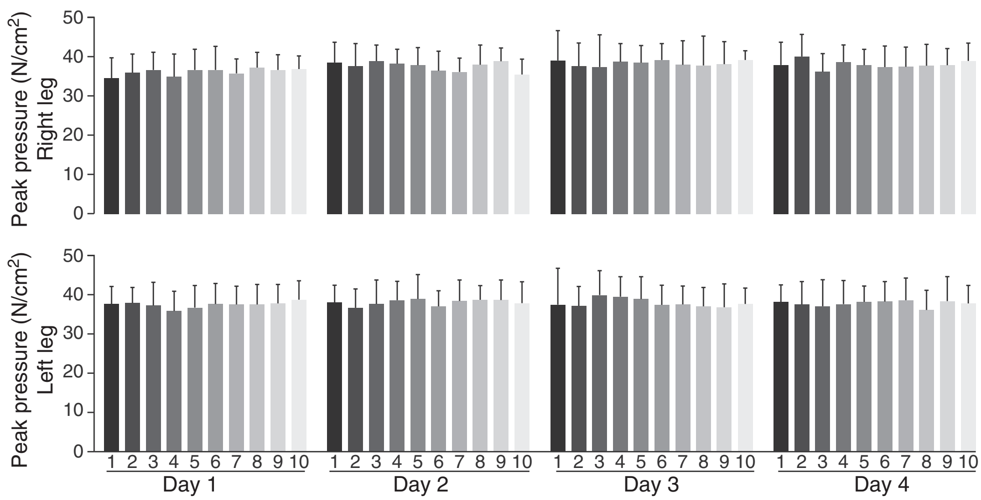

Fig. 4 – Comparison of peak plantar pressures between footsteps for each day. Mean (columns) and standard deviation (vertical lines) for peak pressure (N/cm^2) considering 10 footsteps each day, for right (top line) and left (bottom line) leg. *Indicates difference between footsteps.

the foot in contact with the ground. The evaluation of different regions of the foot, although with a more complex use in a clinical setting, can also provide additional results on this issue. The method used in this study sought to bring the result of what is most often seen in geriatric offices and clinics, where the assessment tools tend to consider the measure of the whole foot, optimizing the data processing time, as well as facilitating the instrumentation handling. Ours was a small group of participants (10 seniors), but the uniformity of the measures is a factor that should be considered in our analyzes. If the measures had a very high variability, the likelihood of a bias in the statistical analysis would be great, which does not seem to be the case in this study.

The asymmetry index observed was similar throughout the days and footsteps. Even being of low magnitude, the predominance of asymmetries on the responses of cushioning mechanisms of lower limbs can affect the mechanical loads experienced,[23,24] especially those incident on the soft tissues of plantar area.[5,9] Taking into account that the elderly people have a slower walking speed versus young adults and thus their feet experience mechanical loads for longer during the stance phase,[25] the observed asymmetries may be a risk factor for future plantar lesions.[26]

Gurney et al.[16] investigated the reliability of plantar pressure measurement during gait of a normal and independent population in 5 different days, concluding that the measures have satisfactory repeatability for use in clinical studies. Our results also suggest that plantar pressure assessment and its variability are presented in a quite consistent way in the elderly, comparing data from evaluations conducted in 4 non-consecutive days. In a way, this scheme facilitates the decision making process based on clinical measurements and assessments of the elderly feet carried out during the evaluation of barefoot gait in a single day. In addition, the plantar pressure measurement that takes into account the total area of the foot increases the reliability in the evaluation among different examiners,[27] since this strategy eliminates the subjectivity often present in the definition of foot areas.

Our study has some limitations. Although critical to the achievement of our goal, the completion of measures in several days, in the search of a similar interval between assessments, eventually limited the number of participants included, because many seniors could not be evaluated at the desired time interval. The plantar pressure measurement in barefoot walking can be a limitation, since people walk with shoes in their everyday lives. However, we made this choice in order to minimize the influence of different types of shoes worn by the elderly in our data, since it would be difficult to require the use of the same type of footwear for the whole group of seniors. Finally, although the pressure measurement of the total area of the foot may be suitable for the kind of evaluation carried out,[27] it would be interesting to consider the analysis of specific areas of the foot, especially regarding the location of pressure peaks.

Conclusion

The elderly in this experiment had a similar gait pattern in different days, both for mean and peak pressures, with asymmetry indexes also similar among the different days evaluated. The repeatability of the asymmetry indexes in the elderly suggests that this population is consistently exposed to asymmetric loads during locomotion, and result fosters the need for future research in this area.

Funding

Fundação de Amparo à Pesquisa do Estado do Rio Grande do Sul (FAPERGS, process n. 1013100) through funding provided for FPC.

Conflicts of interest

The authors declare no conflicts of interest.

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