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Effect of conventional proprioceptive training versus exergames on plantar pressure distribution in older women

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Highlights

- *Improved plantar pressure distribution in both the conventional proprioceptive training group and the exergame group.*
- *Baropodometric analysis demonstrated a significant increase in plantar contact area in both static and dynamic positions with conventional training.*
- *Baropodometric analysis demonstrated a reduction in peak pressure and mean contact pressure on the plantar surface with conventional training.*
- *No significant differences were found between conventional training and exergame training with respect to the studied outcomes.*

Graphical Abstract

Abstract

The present study aimed to evaluate and compare the effects of conventional proprioceptive training and exergame-based training on plantar pressure distribution in older women. This was a randomized controlled clinical trial with 50 older women randomized into three groups: conventional proprioception (n = 17), exergames (n = 16), and control (n = 17). Participants underwent 24 intervention sessions, three times per week, over eight weeks. The conventional proprioception group performed exercises involving gait, balance, and proprioception in the form of a circuit. The exergame group performed exercises using the Microsoft® Xbox Kinect One video game console. Plantar pressure distribution was assessed using the Footwork Pro® electronic baropodometer (Arkipelago). Both conventional proprioceptive training and exergame-based training positively influenced plantar pressure distribution in older women compared to the control group. Both interventions may promote improvement in plantar pressure distribution in older women.

Keywords: Proprioception. Aging. Baropodometry. Circuit-Based Exercise. Exergames.

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INTRODUCTION

As individuals age, there is a progressive decline in motor capacity, in addition to an increased risk of developing conditions that affect the sensory and motor control of the feet[1,2]. The foot is one of the most important structures for weight-bearing and shock absorption, enabling individuals to perform activities on different support surfaces[3]. Significant changes occur in the structure and function of the foot with advancing age, which alter plantar pressure distribution, impairing its normal functions of shock absorption and body weight support, and potentially leading to pathologies and deformities affecting the feet, such as pain, stress fractures, calluses, and ulcerations[4].

Regular physical exercise has been considered an important contributor to health, as it reduces potential disease risks and enhances functional capacity and quality of life in older adults[5]. Among physical exercises, conventional proprioceptive training is particularly notable, as the instability of movements activates proprioceptive impulses that are integrated in various sensorimotor centers, promoting positive effects on functionality and, consequently, reducing falls in older adults[6,7].

Another widely used training resource is exergames. This modality is described as interactive exercise-based games that provide individuals with the opportunity to develop, in a virtual environment, a diverse range of activities, generating social, cognitive, and physical benefits such as improved balance, gait, and coordination[8,9,10].

However, few studies have investigated the influence of specific exercises on plantar pressure distribution in older women. In this context, it is necessary to evaluate whether different modalities of proprioceptive training (conventional and exergame) provide benefits for plantar pressure distribution in older women, as well as to determine which modality is most effective with respect to the studied variables. The present study aimed to evaluate and compare the effects of conventional and exergame-based proprioceptive training on plantar pressure distribution in this population.

MATERIALS AND METHODS

Study design

This study was a randomized controlled clinical trial, developed in accordance with the recommendations of the CONSORT (Consolidated Standards of Reporting Trials)[11], conducted by physical therapists and physical education professionals.

Study setting

The study was conducted in the municipality of Jequí, located in the interior of the state of Bahia, in its Centro-Sul mesoregion, 365 km from the state capital. The site where the interventions and assessments of the older women were carried out was the Convento Santuário Jesus Crucificado, located in the Jequiezinho neighborhood. The convent was selected due to its spacious facilities, including an events hall and several rooms, which constituted one of the favorable aspects for the assessments and development of the proposed training protocols. In addition to the availability of space, its proximity to the Universidade Estadual do Sudoeste da Bahia facilitated the logistics of commuting and participation by collaborators and researchers involved in the study.

Study sample

Participants were older women from four Senior Social Groups (Grupos de Convivência da Terceira Idade), included according to the following criteria: a) maximum age of 79 years; b) no engagement in any modality of physical exercise in the preceding three months; c) absence of cognitive impairment, diabetes mellitus, vestibular disorders, cardiovascular diseases, or visual or auditory impairment; d) independent ambulation without assistive devices. Older women who participated in another proprioceptive rehabilitation program during the training period or in the preceding three months, and those with less than 75% attendance in the training program, were excluded from the study.

Sample size was determined based on the results of a pilot study with 15 older women (5 per group), using as the primary outcome the difference (i.e., performance before training or control minus performance after training or control) in the Timed Up and Go Test (TUGT). The sample size calculation considered $\alpha = 0.05$ and statistical power $(1-\beta) = 0.95$ for 3 groups (control vs. conventional vs. exergame), yielding a sample size of 36 individuals (i.e., 12 per group). Accounting for a potential 25% sample attrition over the 8-week intervention period, the estimated sample size per group was 15 older women (i.e., a total sample of 45 older women). Sample size calculation was performed using G*Power® software, version 3.1.

Following screening according to the established criteria, from a total of 155 older women partici-

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pating in the social groups, 50 remained and were subjected to stratified randomization by age (60–69/70–79 years) and BMI (low/high) to maximize homogeneity across groups. Subsequently, block randomization was performed using Microsoft Excel® software, version 2024, distributing participants across the three study arms (control group, conventional group, and exergame group). The entire process was carried out by a researcher with no clinical involvement in the trial.

The control and conventional groups comprised 17 participants each, and the exergame group comprised 16 participants; at the end of the study, each group had 15 participants. Losses were attributable to attendance below 75% of the training program (3 older women) and voluntary withdrawal (2 older women), totaling 5 losses.

Training protocol

The control group (CTG) did not participate in any training modality during the intervention period; the conventional group (CVG) participated in conventional proprioceptive training; and the exergame group (EXG) participated in proprioceptive training based on virtual reality. Training was performed three times per week over 8 weeks, totaling 24 sessions of 50 minutes each, with a minimum interval of 48 hours between sessions. The training protocol was organized as follows: warm-up (10 min), training (30 min), and cool-down (10 min), with monitoring of blood pressure and heart rate before and after activities.

The conventional proprioceptive training protocol involved gait, balance, and proprioception training, spatially organized as a circuit with different textures and obstacles, comprising seven stations. Participants performed specific exercises at each station in groups of two or three, combining sensory and motor stimulation. The level of difficulty was progressively increased throughout the training by increasing the execution speed of the activities. In all sessions, each older woman was accompanied by a researcher, and each participant's physical capacity and performance were taken into account. The conventional training exercises were based on protocols established in the literature[7,12].

Exergame training was performed using the Microsoft® Xbox Kinect One video game console. This console uses motion sensor technology — the Kinect — which captures players' movements, being sensitive to changes in direction, speed, and acceleration, thus enabling games to be controlled by body movement without the use of a manual controller[13].

The game used was Kinect Sports Rivals, which simulates six sports activities: jet ski racing, climbing, football, bowling, tennis, and target shooting. Game selection was guided by analyses of the motor demands offered by each activity, encompassing basic to more complex motor skills that stimulate coordination, balance, stability, and proprioception. Each session consisted of training with three pre-selected games chosen by lottery, each lasting 10 minutes, for a total of 30 minutes.

Variable assessment

Plantar pressure distribution was assessed using electronic baropodometry, which consists of a force platform that analyzes the distribution and measurement of plantar pressure, body oscillation, and temporal and spatial gait variables. Pressure recordings were obtained using the Footwork Pro® electronic baropodometer (Arkipelago), which has the following characteristics: rigid polycarbonate-coated base with dimensions of 565 × 420 × 25 mm, active surface of 490 × 490 mm, consisting of 4,096 calibrated capacitive sensors, a sampling frequency of 200 Hz, and a maximum pressure per sensor of 120 N/cm^2.

Assessments were performed in both static and dynamic conditions. In the static assessment, the platform was placed one meter from the wall, and participants, barefoot and wearing light clothing, were instructed to stand comfortably in an orthostatic position on the platform, without talking or moving, looking at a point fixed on the wall at eye level and with arms aligned along the body, as recommended in the literature[7,14]. In the dynamic assessment, older women were instructed to walk barefoot and, upon reaching the platform, to step first with the right foot on the outward path and with the left foot on the return.

From the recordings, the following baropodometric variables were used in the static examination: plantar load distribution (%), mean plantar pressure (kgf/cm^2), peak plantar pressure (kgf/cm^2), and plantar contact surface area (cm^2) of the right and left feet, with eyes open and closed. In the dynamic assessment, the following were used: mean plantar pressure (kgf/cm^2), peak plantar pressure (kgf/cm2), and plantar contact surface area (cm^2) of the right and left feet.

Outcome assessments were performed at two time points: before training (T0) and after training (T1), by researchers who did not participate in the allocation process and had no contact with the treatment groups. For the CTG, participants were assessed and reassessed during the same period and at the same location established for the intervention groups.

Statistical procedures

To evaluate the homogeneous distribution of quantitative variables (age and BMI) at baseline across the three groups (control, conventional, exergame), analysis of variance (ANOVA) and Kruskal–Wallis tests were employed following verification of data normality using the Shapiro-Wilk test. Pearson's chi-squared test and Fisher's exact test were used to compare categorical variables between groups at study baseline.

For inferential analysis (parametric or non-parametric) of comparisons of baropodometric variables, the Shapiro-Wilk test was initially applied to assess data normality. Within-group comparisons between two paired samples were performed using the paired Student's t-test or the Wilcoxon signed-rank test. Between-group comparisons among three independent samples were performed using one-way ANOVA with Tukey's post hoc test, or the Kruskal-Wallis test with Dunn's post hoc test.

In cases where dependent variables (dynamic baropodometry) showed significant differences at baseline, analysis of covariance (ANCOVA) was performed, using the initial measurements of these variables (T0) as covariates to control their effect on the mean differences (T1−T0) between groups. In the event of statistical significance, Sidak's post hoc test was applied.

Effect size calculation was performed for between-group comparisons (i.e., comparisons of differences between T0 and T1), adopting partial eta squared (partial η^2) as the effect size parameter. Effect size interpretation followed the convention of small when η^2 = 0.01, medium when η^2 = 0.06, and large when η^2 = 0.14.

Ethical aspects

This study was approved by the Research Ethics Committee of the Universidade Estadual do Sudoeste da Bahia (UESB), under Opinion No. 2,627,047. The study was registered in the Brazilian Clinical Trials Registry (REBEC) under registration number RBR-592yyp.

RESULTS

Within-group comparisons between T0 and T1 in the control group showed significant differences for MPP-R, PPP-R, MPP-R_DYN, MPP-L_DYN, PPP-R_DYN, PPP-L_DYN, CSA-R_DYN, and CSA-L_DYN, indicating that, at the final assessment, the older women in this group presented significantly higher values for mean pressures and peak pressures, and a reduction in foot contact area in the following variables: bipodal stance (mean pressure R and peak pressure R) and dynamic (mean pressures R and L, peak pressures R and L, and contact surface areas R and L), characterizing a deterioration in static and dynamic plantar pressure distribution in this group (Table 1).

Table 1 - Within-group comparisons (T0 vs. T1) of baropodometric variables for the control group of older women participating in the study. Jequié, Bahia, 2026.

Variable	T0 (baseline)	T1 (post-treatment)	*p*-value
RPD (%)#	51.47 (4.50)	54.80 (8.23)	0.051
LPD (%)#	48.53 (4.50)	45.20 (8.23)	0.051
APD (%)#	41.33 (8.65)	42.67 (9.93)	0.201
PPD (%)#	58.67 (8.65)	57.33 (9.93)	0.201
MPP-R (kgf/cm²)#	0.48 (0.14)	0.53 (0.14)	0.024
MPP-L (kgf/cm²)#	0.45 (0.10)	0.47 (0.09)	0.261
PPP-R (kgf/cm²)#	1.84 (0.56)	2.36 (0.60)	0.002
PPP-L (kgf/cm²)#	1.88 (0.52)	2.10 (0.55)	0.066
CSA-R (cm²)#	102.50 (15.83)	99.02 (12.15)	0.135
CSA-L (cm²)#	98.30 (15.12)	96.28 (12.65)	0.216
MPP-R_DYN (kgf/cm²)*	1.61 (0.33)	2.10 (0.85)	0.001
MPP-L_DYN (kgf/cm²)*	1.60 (0.25)	2.27 (0.53)	0.001
PPP-R_DYN (kgf/cm²)*	3.51 (0.30)	4.02 (1.15)	0.001
PPP-L_DYN (kgf/cm²)*	3.81 (0.65)	4.12 (1.31)	0.023
CSA-R_DYN (cm²)#	116.62 (14.38)	98.83 (17.71)	<0.001
CSA-L_DYN (cm²)*	110.20 (16.82)	99.76 (28.42)	0.001

PPD = posterior plantar distribution; MPP-R = mean plantar pressure right foot; MPP-L = mean plantar pressure left foot; PPP-R = peak plantar pressure right foot; PPP-L = peak plantar pressure left foot; CSA-R = contact surface area right foot; CSA-L = contact surface area left foot; DYN = dynamic; #Mean (standard deviation), paired Student's t-test; *Median (interquartile range), Wilcoxon signed-rank test.

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Within-group comparisons between T0 and T1 in the conventional group showed significant differences for APD, PPD, MPP-R, MPP-L, PPP-R, PPP-L, CSA-R, CSA-L, MPP-R_DYN, MPP-L_DYN, PPP-R_DYN, PPP-L_DYN, CSA-R_DYN, and CSA-L_DYN, indicating that, at the end of the intervention, the older women in this group showed significantly better values in the following variables: bipodal stance (anteroposterior load distribution, mean pressures R and L, peak pressures R and L, and contact surface areas R and L) and dynamic (mean pressures R and L, peak pressures R and L, and contact surface areas R and L), characterizing improved static and dynamic plantar pressure distribution in this group (Table 2).

Table 2 - Within-group comparisons (T0 *vs.* T1) of baropodometric variables for the conventional group of older women participating in the study. Jequié, Bahia, 2026.

Variable	T0 (*baseline*)	T1 (pós-tratamento)	*p*-valor
RPD (%)[#]	52.27 (8.84)	50.47 (2.26)	0.415
LPD (%)[#]	47.73 (8.84)	49.53 (2.26)	0.415
APD (%)[*]	45.00 (9.00)	42.00 (5.00)	0.010
PPD (%)[*]	55.00 (9.00)	58.00 (5.00)	0.010
MPP-R (Kgf/cm²)[#]	0.48 (0.09)	0.43 (0.09)	0.007
MPP-L (Kgf/cm²)[#]	0.47 (0.12)	0.40 (0.09)	0.001
PPP-R (Kgf/cm²)[#]	1.84 (0.54)	1.51 (0.34)	0.002
PPP-L (Kgf/cm²)[#]	1.92 (0.46)	1.61 (0.44)	<0.001
CSA-R (cm²)[#]	95.16 (11.71)	99.27 (12.20)	0.007
CSA-L (cm²)[#]	94.62 (11.96)	99.40 (10.83)	0.001
MPP-R_DYN (Kgf/cm²)[#]	1.72 (0.26)	1.45 (0.35)	0.009
MPP-L_DYN (Kgf/cm²)[#]	2.14 (0.45)	1.56 (0.30)	0.001
PPP-R_DYN (Kgf/cm²)[#]	4.35 (0.69)	3.40 (0.55)	<0.001
PPP-L_DYN (Kgf/cm²)[#]	4.48 (0.87)	3.44 (0.39)	0.001
CSA-R_DYN (cm²)[#]	101.38 (12.41)	107.84 (11.96)	0.023
CSA-L_DYN (cm²)[#]	99.60 (15.10)	106.64 (14.38)	0.008

RPD = right plantar distribution; LPD = left plantar distribution; APD = anterior plantar distribution; PPD = posterior plantar distribution; MPP-R = mean plantar pressure right foot; MPP-L = mean plantar pressure left foot; PPP-R = peak plantar pressure right foot; PPP-L = peak plantar pressure left foot; CSA-R = contact surface area right foot; CSA-L = contact surface area left foot; DYN = dynamic; [#]Mean (standard deviation), paired Student's t-test; [*]Median (interquartile range), Wilcoxon signed-rank test.

Within-group comparisons between T0 and T1 in the exergame group showed significant differences for MPP-R, MPP-L, PPP-R, CSA-R, CSA-L, MPP-R_DYN, MPP-L_DYN, PPP-R_DYN, PPP-L_DYN, and CSA-L_DYN, indicating that, at the end of the intervention, the older women in this group showed significantly better values in the following variables: bipodal stance (mean pressures R and L, peak pressure R, and contact surface areas R and L) and dynamic (mean pressures R and L, peak pressures R and L, and contact surface area L), characterizing improved static and dynamic plantar pressure distribution in this group (Table 3).

It is important to note that, among the significant differences found in the baropodometric variables for both the conventional training and the exergame groups, no results were observed that negatively influenced plantar pressure distribution in the older women.

Comparative analysis of changes in baropodometric variables showed significant differences between groups. For mean pressures R and L, peak pressures R and L, and contact surface areas R and L in static and dynamic stance, the results demonstrated a superior effect of conventional training and exergame training compared to the control group (Table 4).

Among all variables studied, no significant differences were observed between the conventional and exergame groups, indicating a similar effect of both training modalities. With respect to effect size, results indicate a large effect for all variables that showed significant differences (0.173–0.582) (Table 4).

Table 3 - Within-group comparisons (T0 vs. T1) of baropodometric variables for the exergame group of older women participating in the study. Jequié, Bahia, 2026.

Variable	T0 (baseline)	T1 (post-treatment)	*p*-value
RPD (%)[#]	50.67 (8.62)	48.00 (5.40)	0.193
LPD (%)[#]	49.33 (8.62)	52.00 (5.40)	0.193
APD (%)[#]	44.67 (10.67)	46.40 (9.48)	0.112
PPD (%)[#]	55.33 (10.67)	53.60 (9.48)	0.112
MPP-R (kgf/cm^2)[#]	0.53 (0.11)	0.46 (0.11)	<0.001
MPP-L (kgf/cm^2)[#]	0.54 (0.11)	0.49 (0.10)	0.002
PPP-R (kgf/cm^2)[*]	2.14 (0.55)	1.78 (0.63)	0.023
PPP-L (kgf/cm^2)[#]	2.17 (0.42)	1.99 (0.40)	0.150
CSA-R (cm^2)[#]	91.45 (15.96)	95.35 (16.88)	0.041
CSA-L (cm^2)[#]	89.20 (19.33)	94.19 (18.73)	0.007
MPP-R_DYN (kgf/cm^2)[*]	2.03 (0.45)	1.66 (0.57)	0.005
MPP-L_DYN (kgf/cm^2)[*]	2.04 (0.91)	1.59 (0.44)	0.003
PPP-R_DYN (kgf/cm^2)[#]	4.38 (0.74)	3.74 (0.42)	0.003
PPP-L_DYN (kgf/cm^2)[#]	4.31 (0.73)	3.59 (0.34)	0.004
CSA-R_DYN (cm^2)[#]	98.88 (18.71)	102.85 (18.72)	0.087
CSA-L_DYN (cm^2)[#]	95.51 (20.50)	105.29 (19.57)	0.001

RPD = right plantar distribution; LPD = left plantar distribution; APD = anterior plantar distribution; PPD = posterior plantar distribution; MPP-R = mean plantar pressure right foot; MPP-L = mean plantar pressure left foot; PPP-R = peak plantar pressure right foot; PPP-L = peak plantar pressure left foot; CSA-R = contact surface area right foot; CSA-L = contact surface area left foot; DYN = dynamic; [#]Mean (standard deviation), paired Student's t-test; [*]Median (interquartile range), Wilcoxon signed-rank test.

Table 4 - Between-group comparisons of changes (T1−T0) and effect size of baropodometric variables of the older women participating in the study. Jequié, Bahia, 2026.

Variable	Control	Conventional	Exergame	*p*-value	Partial η^2
RPD (%)[#]	3.33 (6.04)[a]	-1.80 (8.30)[a]	-2.67 (7.54)[a]	0.065	0.122
LPD (%)[#]	-3.33 (6.04)[a]	1.80 (8.30)[a]	2.67 (7.54)[a]	0.065	0.122
APD (%)[*]	1.00 (6.00)[a]	-3.00 (6.00)[a]	3.00 (5.00)[a]	0.084	0.217
PPD (%)[*]	-1.00 (6.00)[a]	3.00 (6.00)[a]	-3.00 (5.00)[a]	0.084	0.217
MPP-R (kgf/cm^2)[*]	0.03 (0.10)[a]	-0.04 (0.08)[b]	-0.07 (0.06)[b]	<0.001	0.317
MPP-L (kgf/cm^2)[#]	0.02 (0.05)[a]	-0.06 (0.06)[b]	-0.05 (0.04)[b]	<0.001	0.305
PPP-R (kgf/cm^2)[#]	0.52 (0.54)[a]	-0.33 (0.33)[b]	-0.30 (0.45)[b]	<0.001	0.450
PPP-L (kgf/cm^2)[#]	0.21 (0.41)[a]	-0.31 (0.24)[b]	-0.17 (0.43)[b]	0.001	0.271
CSA-R (cm^2)[#]	-3.48 (8.50)[a]	4.11 (5.04)[b]	3.90 (6.70)[b]	0.006	0.219
CSA-L (cm^2)[#]	-2.02 (6.05)[a]	4.78 (4.33)[b]	4.99 (6.10)[b]	0.001	0.269
MPP-R_DYN (kgf/cm^2)[+]	0.57 (0.85)[a]	-0.32 (0.79)[b]	-0.25 (0.87)[b]	<0.001	0.535
MPP-L_DYN (kgf/cm^2)[+]	0.32 (0.76)[a]	-0.44 (0.69)[b]	-0.37 (0.71)[b]	<0.001	0.499
PPP-R_DYN (kgf/cm^2)[+]	0.65 (1.23)[a]	-0.79 (1.13)[b]	-0.47 (1.14)[b]	<0.001	0.582
PPP-L_DYN (kgf/cm^2)[+]	0.61 (1.91)[a]	-0.78 (1.86)[b]	-0.61 (1.82)[b]	0.003	0.362
CSA-R_DYN (cm^2)[+]	-16.08 (19.07)[a]	5.80 (7.77)[b]	2.93 (8.13)[b]	<0.001	0.546
CSA-L_DYN (cm^2)[+]	-12.46 (18.32)[a]	6.66 (7.42)[b]	8.82 (7.85)[b]	<0.001	0.534

RPD = right plantar distribution; LPD = left plantar distribution; APD = anterior plantar distribution; PPD = posterior plantar distribution; MPP-R = mean plantar pressure right foot; MPP-L = mean plantar pressure left foot; PPP-R = peak plantar pressure right foot; PPP-L = peak plantar pressure left foot; CSA-R = contact surface area right foot; CSA-L = contact surface area left foot; DYN = dynamic; [#]Mean difference T1−T0 (standard deviation), one-way ANOVA, Tukey's post hoc; + Mean difference T1−T0 (standard deviation), ANCOVA, Sidak's post hoc; [*]Median difference T1−T0 (interquartile range), Kruskal–Wallis test, Dunn's post hoc; [a,b]Different letters in the same row indicate a statistically significant difference between groups ($p \leq 0.05$); partial η^2 = effect size.

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DISCUSSION

Plantar pressure distribution is one of the kinetic variables that determines the magnitude and location of ground reaction forces on the plantar surface, providing valuable information about how the foot interacts with the ground during gait, reflecting balance, muscle function, and postural control, particularly in older populations[15].

The results of the present study showed that both conventional proprioceptive training and exergame-based training positively influenced plantar pressure distribution in older women compared to the control group. The positive effects obtained from the proprioceptive training modalities proposed in this study may facilitate movement control, as the number of plantar sensory receptors in contact with the ground increases, providing the nervous system with more precise peripheral information, which enables a better distribution of pressure peaks and, consequently, promotes stability during gait and activities of daily living, potentially making older adults less prone to falls[7,16].

In the conventional training group of this study, improvement was observed in 14 out of 16 baropodometric variables in both static and dynamic assessments, resulting in a better anteroposterior load distribution of the feet, reduction of mean pressures and plantar pressure peaks, and an increase in the plantar contact surface area with the ground.

The relationship between plantar contact area and plantar pressure is inversely proportional. This means that, for the same force (body weight), the smaller the foot contact area with the ground, the greater the pressure exerted on that area, and vice versa. Therefore, monitoring contact area is fundamental for understanding load distribution and preventing excessive pressure on soft tissues, which is crucial in injury prevention[16,17].

In accordance with the study by Alfieri *et al.*[16], who examined the effects of a conventional proprioceptive exercise program in sedentary older adults, a significant increase in plantar contact surface area and a reduction in peak plantar pressure were observed through baropodometry. According to the authors, the increase in plantar contact area promotes a better distribution of contact pressure peaks. High pressure peaks on the feet are associated with the need for clinical attention due to their potential to cause injury to plantar tissue, suggesting that this relationship between contact area and plantar pressure may be more favorably distributed following conventional proprioceptive interventions, making older adults less likely to develop calluses that could interfere with postural control[16].

Regarding anteroposterior load redistribution of the feet in bipodal stance, the results showed that, with conventional training, load shifted from 55% to 58% in the rearfoot region and from 45% to 42% in the forefoot region in the older women. Normal values for load distribution in the heel region are higher than in the anterior region of the foot. According to Tortora and Nielsen18, normal values for plantar pressure distribution are approximately 60% in the posterior foot region and 40% in the anterior foot region.

In light of the normative values presented in the literature, the present study demonstrated improved plantar load distribution between the forefoot and rearfoot in the group of older women who practiced conventional training. Thus, this type of training may contribute positively to plantar pressure distribution, as this modality promotes improvement in muscle reactivity and neuromuscular recruitment patterns, activating proprioceptive impulses that are integrated into various sensorimotor centers, thereby constituting a viable exercise option for older adults[19,20].

In the exergame training group, improvement was observed in 10 baropodometric variables in both static and dynamic assessments, resulting in a reduction of mean pressures and plantar pressure peaks, and an increase in the plantar contact surface area with the ground. The positive effects on plantar pressure distribution obtained in the older women of the present study through exergame training may be explained, among other factors, by the performance of activities involving lower limb weight-bearing, anteroposterior and mediolateral displacement of the center of gravity, multidirectional steps, squatting, turns and jumps, movements of the upper limbs and head, and balance control, in addition to stimulation of cognitive functions such as attention, planning, and reaction time[21,22].

Exergame intervention exercises promote immediate interaction, and the cognitive-motor dual-task training components in exergames may have resulted in improved balance performance in participants. In this exercise modality, both physical and psychological functions are trained. Playing exergames involves dual-task training, as players must move in different directions in response to game content to score points, using the instantaneous audio and visual feedback of the game, through which players learn to improve their balance skills[10,23].

Virtual rehabilitation offers the benefit of multisensory stimulation through visual and auditory stimuli, in addition to fostering engagement in tasks with a greater number of repetitions due to their playful nature[10]. According to Adamovich *et al.*[24], repetition facilitates movement production through neurophysiological and behavioral modifications arising from neuroplastic mechanisms, and constitutes an important variable in the relearning of motor skills. Thus, the improvement in plantar pressure distribution promoted by virtual reality exercises may enhance somatosensory afferents of the feet, contributing to the facilitation of postural control and, consequently, to a reduction in fall risk among older adults.

With respect to plantar pressures and plantar contact surface area, an increase in plantar contact surface area and a reduction of mean pressures and pressure peaks were observed in both the conventional proprioceptive training group and the virtual reality group, regardless of static position or gait. These data suggest that both types of intervention, through sensorimotor stimulation - with particular emphasis on conventional training, which yielded positive effects across a greater number of variables - promoted a better distribution of the pressure intensity applied to the plantar surface.

In the control group, deterioration was observed in 8 baropodometric variables during the evaluation period, in both static and dynamic assessments, resulting in increases in mean pressures and plantar pressure peaks, reduction in foot contact surface area, and poorer plantar load distribution. The absence of regular physical exercise during this period of the study may have increased the likelihood of further declines in cognitive abilities and motor performance with aging, thereby impairing the plantar distribution-related variables in these older women[15].

Alterations in plantar pressure distribution in older adults may increase the risk of falls, since during gait the foot is the only structure of the human body in contact with the ground, and increased plantar pressure is one of the factors that disrupts normal foot function, affecting proprioception and sensory information from the plantar surface and, consequently, impairing stability and body balance[25].

When comparing between-group results, both training modalities demonstrated a superior effect on baropodometric variables compared to the control group, with no significant differences between the intervention groups. These findings indicate two training modalities with different approaches — one focused on exercise performance in a real environment, and the other on exercise performance in virtual environments — both of which provided better conditions for adaptation of plantar load distribution in older women.

Both training modalities are easily reproducible and aim to improve the functionality of older adults. Conventional training maintains its importance, as the group of older women subjected to this intervention achieved significant improvements in the assessed aspects; on the other hand, exergame training, by yielding positive results on baropodometric variables, constitutes an additional resource and may represent a further alternative in the management of plantar pressure dysfunction in older women.

CONCLUSIONS

It was concluded that the older women showed improvement in baropodometric variables, achieving, overall, a better plantar pressure distribution in both the conventional proprioceptive training group and the exergame training group. Baropodometric analysis demonstrated a significant increase in plantar contact area in both static and dynamic positions, as well as a reduction in peak pressure and mean contact pressure on the plantar surface, particularly in the conventional training group. When comparing between-group results, a superior effect was observed in the intervention groups compared to the control group; however, no significant differences were found between conventional training and exergame training with respect to the studied outcomes.

CRediT author statement

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the workreported in this paper.

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