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Analysis of plantar pressure during dynamic squat movement in asymptomatic volleyball athletes before and after fatigue protocol

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ABSTRACT

Background: Fatigue is a common condition during physical activity, resulting in reduced muscle strength, motor control, balance and coordination. Changes in plantar pressure are often related to fatigue and may also increase the risk of injury. **Objective:** To evaluate the changes in baropodometry during the squat movement. The hypothesis is that pressure and load will be higher in the non-dominant leg post fatigue **Methods:** 28 volunteers of both sexes were recruited, all active participants of the university volleyball team. The plantar pressure distribution was measured during three squat movements. The evaluation was performed before and after the fatigue protocol, which consisted in four series of fifteen seconds of jump with ten seconds of rest between the series. Statistical analysis was performed using the statistical package PASW 19.0 (SPSS inc.) with significance level adopted at 5% ($p \leq 0,05$). **Results:** For females, there was a significant reduction of 12% in mean pressure of dominant limb. For males, significant reductions in mean pressure of dominant limb (7,1%) and non-dominant limb (9,5%) and peak pressure of dominant (13,8%) and non-dominant limb (10,1%). **Conclusions:** The fatigue processes reduced plantar pressure during the squat movement, presenting different repercussions between sexes, but both able to predispose to injury.

Keywords: Kinetics; Pressure; Fatigue; Sports; Biomechanics

BACKGROUND

The distribution of plantar pressure differs between static posture and dynamic activity. Static assessment indicates increased center of gravity and hindfoot pressure^(1,2). The dynamic assessment suggests an increase in peak pressure in the forefoot region⁽³⁾. However, we are not aware of studies that assess the effects of fatigue on plantar pressure specifically during the dynamic squat movement.

Previous studies have analyzed the effects of plantar pressure between dominant and non-dominant limbs in soccer players demonstrating that feet behave differently during sports movements, suggesting that the dominant foot is used to generate force during sports movement and the non-dominant limb used for body stabilization⁽⁴⁾.

Fatigue can be defined as the muscular inability to maintain the mechanical work necessary for a given task⁽⁵⁾. Fatigue results in reduced physical performance, through decreased muscle strength, motor control, balance and coordination⁽⁶⁾. This loss of muscle efficiency is common during physical activity and

can change, among other factors, kinetic variables such as plantar pressure distribution, which may be related to the occurrence of injuries such as tibial stress⁽⁷⁾ inversion sprains^(1,2) and metatarsal stress fracture⁽³⁾.

In this sense, several authors have investigated the influence of fatigue on biomechanical variables during static and dynamic activities, among the different movement changes observed is the increase in the plantar pressure area and center of gravity^(1,2,6). The squat is an important movement used in many rehabilitation programs and in many sports. Understanding the effects of fatigue on kinetic variables is extremely important, including for comprehending possible harmful mechanisms during the performance of this exercise.

Thus, the present study aims to analyze fatigue-related changes in plantar pressure distribution during the free squat movement in healthy volleyball athletes, in addition to comparing how the sample behaves in both sexes (men and women).

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METHODS

Volunteers

The present study is a cross-sectional study. Twenty-eight volunteers participated in this research, 12 women (23.2 ± 5.0 years) and 16 men (23.2 ± 3.6 years), college students, volleyball athletes, asymptomatic (absence of previous injuries in the lower limb over the last 6 months), with no chronic injuries or joint instability, who were actively training with their respective teams.

Baropodometrics

The subjects performed three free squat movements on the EPS baropodometric platform (Kinetec®, Porto Alegre, BR) with a dimension of 675 x 540 x 5mm, active area of 480 x 480mm, and with 2304 resistive sensors with an acquisition frequency of 100 Hz. Squats were performed by bending the knee at least 90 degrees, with the upper limbs free to avoid loss of balance that would alter the assessment. The average of these procedure was calculated from these three movements before and after the fatigue protocol.

Experimental Fatigue Protocol

The fatigue experimental protocol followed the description from the one performed by Bosco et al. ⁽⁸⁾ The protocol consisted of performing four sets of vertical jumps for 60 seconds, with counter movement and a ten-second interval between each set. To standardize the angular displacement of the knee during the contact phase, the subject had to bend the knee about 90 degrees. To avoid changes during movement, horizontal and lateral displacements were minimized and hands should be kept on the hips throughout the jump.

Procedures

Initially, data collection was performed to obtain anthropometric data and characterize the sample (Table 1). Subsequently, the evaluation was performed on the EPS baropodometric platform (Kinetec®), which consisted of three free squat movements with both legs inside the platform, upper limbs free throughout the squat phase. After the initial assessment, the volunteers were submitted to a fatigue protocol following the recommendations proposed⁽⁸⁾.

After applying the fatigue protocol, each volunteer performed the evaluation on the EPS

baropodometer (Kinetec®) again, following exactly the same processes as the initial evaluation, with the execution of three free squat movements on the baropodometric platform.

Data processing

The visualization and processing of plantar pressure variables were obtained through the analysis software of the platform system itself. The values used for analysis were related to pressure measurements (kPA), load (% of body weight) and contact surface (cm²). The load values were determined for Frontal plane load of the dominant limb (Fidl), Frontal plane load of non-dominant limb (FIndl), Sagittal plane load of the forefoot (Slff) and Sagittal plane load of the hindfoot (Slhf).

The pressure values were subdivided into Maximum pressure on dominant limb (MpdI), Maximum pressure on non-dominant limb (MpndI), Average pressure on dominant limb (ApdI) and Average pressure on non-dominant limb (ApndI).

Statistical analysis

Quantitative variables are described by average and standard deviation (SD). The distribution of normality was verified by the Shapiro-Wilk test. To compare averages between sexes, the Student's t-test was performed for independent samples. To analyze the effect of the fatigue protocol on baropodometry, the Student's t-test was performed for paired samples. The significance level adopted was 5% ($p \leq 0.05$) and the data were analyzed using the SPSS 19.0 software.

RESULTS

Significant differences were observed between the sexes for height, % fat, body fat (kg) and lean mass, but without differences in relation to age and body weight (Table 1).

When analyzing the effect of the fatigue protocol on the parameters of baropodometry, the Student's t-test identified in females a significant reduction of 12.2% in ApdI ($p=0.048$). For males, there were significant reductions of 7.1% in MpdI ($p=0.041$), 9.5% in MpndI ($p=0.003$), 13.8% in ApdI ($p=0.004$) and 10.1% in ApndI ($p=0.008$). (Table 2)

Table 1. Sample characteristics and comparison of average and standard deviation (SD) by sex.

	Female (n=12)		Male (n=16)		p-value
	Average	SD	Average	SD	
Age	23,2	5,0	23,2	3,6	0,990
Mass (kg)	68,0	13,5	74,4	8,8	0,146
Height (m)	1,68	0,06	1,79	0,05	<0,001*
%Fat	22,1	6,6	11,3	4,5	<0,001*
Fat (kg)	15,8	7,7	8,7	4,9	0,006*
Lean Mass (kg)	52,4	6,1	67,5	8,8	<0,001*

Note: p-value $\leq 0,05$ significant difference between sexes by the Student's t test for independent groups.

Table 2. Comparison of average and standard deviation of baropodometry between pre and post fatigue protocol moments separated by sex.

	Female (n=12)					Male (n=16)				
	Pre		Post		p-value	Pre		Post		p-value
	Average	DS	Average	DS		Average	DS	Average	DS	
Fpdl	44,7	6,0	41,1	5,4	0,053	38,7	7,7	38,4	5,0	0,908
Fpndl	55,3	6,0	58,9	5,4	0,053	61,4	7,7	61,6	5,0	0,908
Slhf	63,5	13,2	64,6	15,5	0,694	69,5	9,4	66,2	11,3	0,314
Slff	36,6	13,2	35,4	15,5	0,694	30,5	9,4	33,8	11,3	0,314
Dcs	81,4	22,3	76,5	22,0	0,214	68,9	27,3	71,8	15,0	0,658
Ndcs	99,9	18,6	99,8	20,3	0,963	111,8	23,8	113,7	18,0	0,652
Mpdl	182,2	25,9	162,0	19,1	0,056	173,0	22,7	160,7	25,4	0,041*
Mpndl	168,4	25,7	166,9	27,6	0,842	176,1	22,8	159,3	18,3	0,003*
Apdl	48,1	8,3	42,3	6,3	0,048*	53,5	8,9	46,1	7,9	0,004*
Apndl	47,7	7,5	46,0	8,0	0,287	51,3	8,7	46,1	5,5	0,008*

Note: p-value ≤ 0.05 significant difference between pre and post moments by Student's t-test for paired groups; Fldl: Frontal load of dominant limb, Flndl: Frontal load of non-dominant limb, Slhf: Sagittal load on hindfoot, Slff: Sagittal load on forefoot, Dcs: Dominant contact surface, Ndcs: Non-dominant contact surface, Mpdl: maximum pressure dominant, Mpndl: maximum non-dominant pressure, Apdl: Average pressure on the dominant limb, Apndl: Average pressure on non-dominant limb.

DISCUSSION

The present study evidenced changes in baropodometric variables after the execution of the fatigue protocol, with the main findings referring to pressure variables, with a significant reduction in average pressure on the dominant limb for female volunteers and reduction in

maximum and average pressure exerted on both members for male volunteers. The reduction in absolute values of the pressure variables (Mpdl, Mpndl, Apdl, Apndl) identified in the present study corroborates in parts with studies by Escamilla⁽⁹⁾, who identified a and a reduction in peak pressure





on the midfoot, medial calcaneus, head of the first metatarsal and hallux, respectively. However, such studies also show, simultaneously, an increase in peak pressure on other areas of the foot, such as the head of the second metatarsal, the head of the third metatarsal and in the medial calcaneus^(7,9).

In the present study, no increase in pressure was found in any region of the foot, probably due to the fact that the volunteers were instructed to use their own mode of execution of the movement, not changing the pattern of the sports gesture normally performed.

Literature presents divergences regarding the changes in plantar pressure after fatigue, which is possibly due to the great diversity of methods used in research, from the fatigue protocol used to the plantar pressure analysis method. Fatigue protocols range from protocols for specific muscles of the ankle^(1,2) and hip⁽¹⁰⁾, to general fatigue protocols, using running itself^(3,7,11,12). The analysis of plantar pressure differs mainly between static⁽¹³⁻¹⁵⁾ and dynamic posture^(16,17), in addition to the use of platforms^(9,18-20) or insoles⁽¹⁰⁾.

Based on previous literature, this study is the first to assess plantar pressure variations during the post-fatigue squat movement. Thus, more studies are needed to enable comparison during this specific gesture. In addition to the difference used in the analysis methods, what may justify the disagreement of results and the reduction in plantar pressure found in the present study is the non-standardization of the range of squat movement, thus, after fatigue, the volunteers may have performed the squat movement in a smaller amplitude when compared to the pre-fatigue condition, reducing the pressure applied to the platform, along with mentioning the limitation of space created by the size of the baropodometry which had a dimension of 675 x 540, with an active area of 480 x 480mm which may be considered insufficient to assess the natural squat of some individuals who need greater abduction to perform the movement.

However, the reduction in plantar pressures for male volunteers may be due to an increase in the contact surface of the feet. The measurement used to assess the contact surface is kPA (Kilopascal). It is known that 1 Kilopascal is equivalent to 0.0101971621297793 kilogram-force/centimeter² (kgf/cm²), whereas the contact surface is measured in square centimeters (cm²), thus, changes in the contact surface will directly influence the average and maximum pressure values exerted on the platform. Since these two quantities are inversely proportional, the increase in the contact surface will result in pressure

reduction, as well as the result obtained in the present study.

Previous studies have identified an increase in the contact surface as a consequence of the fatigue process^(3,7,9). According to Escamilla-Martinez et al.⁽⁹⁾, fatigue produces an increase in the contact surface due to the expansion of soft tissue. Weist et al.⁽³⁾ considers the posterior tibialis muscle to be very important in supporting the longitudinal arch and that its fatigue can lead to changes in the load distribution on the forefoot. Thus, the increase in the contact surface can be explained by the collapse of the longitudinal arch as a consequence of the muscle fatigue process.

However, for female volunteers, both the contact surface and the average pressure of the dominant limb reduced after fatigue, something that is unfeasible since both quantities are inversely proportional.

Observing the load distribution in the frontal plane, we can identify a tendency to redirect the load between the limbs, with a reduction of 8.7% ($p=0.053$) in the dominant limb and an increase of 6.1% ($p=0.053$) in the limb non-dominant, suggesting a greater burden on the non-dominant limb after fatigue for females.

The importance of studying plantar pressure during specific sporting gestures is due to the fact that its alterations may be correlated with an increased risk of injury in athletes. The increased pressure exerted on the medial arch is indicative of increased foot pronation and may be caused by the fatigue process^(3,12,21), changing the kinematics in the sagittal plane⁽²²⁾ and predisposing the athlete to injury⁽²³⁾.

CONCLUSION

Lower limb fatigue reduced plantar pressure during the free squat movement differently between genders, suggesting that even with different patterns, both genders have alterations in plantar distribution that may predispose to injury. However, more studies on plantar pressure during squats are needed to identify the possible clinical effects of this condition. We suggest that in future studies COP analysis, kinematic analysis and standardization of squat range of motion be used.

Authors' contributions:

Órdenes,JA: Responsible for the structure of the article, data collection, article writing and final review. Serrão,R.J.: data collection and article writing; Garcia,G.: data collection and article writing; Oliveira,L.: data collection and article writing; Chagas,E.: data analysis, statistics and article writing. All authors approved the final manuscript and there was no conflict of interest.

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