Original Article

Oscillation of plantar pressure center in athletes and non-athletes with and without ankle sprains[☆]

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ABSTRACT

Objective: To assess whether there is any difference in the oscillation of the plantar pressure center in single-leg stance between athletes and non-athletes with and without ankle sprains.

Methods: 54 volunteers performed four static assessments and one dynamic assessment while standing on one foot on a baropodometer, barefoot, for 10 s in each test. The variables of area (cm^2), distance (cm), anteroposterior oscillation (cm), mediolateral oscillation (cm) and mean velocity (cm/s) were analyzed. The items "other symptoms" and "sports and recreation" of the subjective Foot and Ankle Outcome Score (FAOS) questionnaire were applied. For the statistical analysis, repeated-measurement ANOVA (ANOVA-MR), multivariate ANOVA (MANOVA), Tukey's *post hoc* test and partial eta squared were used.

Results: ANOVA-MR revealed differences regarding distance, with major effects for eyes ($p < 0.001$), knees ($p < 0.001$), group ($p < 0.05$) and the interaction between eyes and knees ($p < 0.05$); and regarding mean velocity with major effects for eyes ($p < 0.001$), knees ($p < 0.001$) ($p < 0.05$), group ($p < 0.05$) and the interaction between eyes and knees ($p < 0.05$). MANOVA revealed main group effects for distance ($p < 0.05$), anteroposterior oscillation ($p < 0.05$) and mean velocity ($p < 0.05$). In the FAOS questionnaire, there were no differences: "other symptoms", $p > 0.05$; and "sport and recreation", $p > 0.05$.

Conclusion: Athletes present higher mean velocity of oscillation of plantar pressure center and generally do not have differences in oscillation amplitude in the sagittal and coronal planes, in comparison with non-athletes.

Oscilação do centro de pressão plantar de atletas e não atletas com e sem entorse de tornozelo

R E S U M O

Palavras-chave:
Traumatismos do tornozelo
Pé
Pressão
Equilíbrio postural

Objetivo: Avaliar se há diferença quanto à oscilação do centro de pressão plantar em apoio unipodal entre atletas e não atletas com e sem entorse de tornozelo.

Método: Fizeram quatro avaliações estáticas e uma dinâmica em apoio unipodal descalço sobre o baropodômetro 54 voluntarios, com duração de 10 segundos cada teste. Foram analisadas as variáveis área (cm^2), distância (cm), oscilação anteroposterior (cm), oscilação mediolateral (cm) e velocidade média (cm/s). Foram aplicados os itens "Outros sintomas" e "Esporte e recreação" do questionário subjetivo Foot and Ankle Outcome Score (FAOS). Para a análise estatística foram usadas a ANOVA de médias repetidas (ANOVA-MR), a ANOVA multivariada (MANOVA), o *post hoc* de Tukey e o *partial eta square*.

Resultados: A ANOVA-MR revelou diferenças para distância, com efeitos principais para olhos ($p < 0,001$), joelho ($p < 0,001$), grupo ($p < 0,05$) e interação olhos e joelho ($p < 0,05$) e para a velocidade média com efeitos principais para olhos ($p < 0,001$), joelho ($p < 0,001$), grupo ($p < 0,05$) e interação olhos e joelho ($p < 0,05$). A MANOVA revelou efeitos principais de grupo para distância ($p < 0,05$), oscilação anteroposterior ($p < 0,05$) e velocidade média ($p < 0,05$). No questionário FAOS não houve diferenças ("Outros sintomas" [$p > 0,05$], "Esporte e eecreação" [$p > 0,05$]).

Conclusão: Atletas apresentam maior velocidade média de oscilação do centro de pressão plantar e não apresentam, de modo geral, diferenças quanto à amplitude de oscilação nos planos sagital e coronal quando comparados com não atletas.

Introduction

Injuries due to ankle sprains may cause neuromuscular and mechanical damage to the joint, predispose to recurrence, and compromise postural control and performance of motor activities.[1–6] Considering the effects of the injury on postural control, individuals with chronic instability present more time for stabilization when compared with individuals without injury, despite not presenting differences regarding oscillations in the sagittal and coronal planes. This last fact possibly occurs because individuals with instability develop compensatory strategies to keep the plantar center of pressure (PCP) within the limits of stability.[7]

Court-based sports require the implementation of complex motor tasks. In order to perform the necessary sporting movement, adequate posture control and stability are very important. Athletes are often not attentive to the supporting surface; thus, sprains are frequent in sports, especially on courts,[8–11] which can compromise stability and postural control. When compared with non-athletes, athletes have lower variability of the center of pressure, *i.e.*, greater stability during unipedal stance, suggesting greater neuromotor demand due to the sport. Another fact is that athletes also have higher mean center of pressure velocity, explained by the principle of stochastic resonance (SR), which may be better developed in athletes.[12]

In the muscle tissue, SR is the ability of sensory noise to potentiate subthreshold sensoriomotor signals in a given stimulated region and allow for an increased threshold, which in turn leads to its detection and consequent response to afferent activity, in this case the contraction.[13,14] Apparently, highly trained athletes who depend on their stability to execute a good motor action have learned how to make use of this feature and, therefore, facilitate a quick contraction. However, to date there are no studies that investigated what occurs in trained athletes with a history of sprains.

In short, despite the rate of high ankle injury per sprain in sports and the importance of postural control, no studies comparing postural control among athletes and non-athletes with and without sprain were retrieved. Therefore, this study aimed to assess whether there is difference in the oscillation of the PCP in unipedal stance among athletes and non-athletes with and without ankle sprain. According to the SR principle, the authors hypothesized that athletes in general have higher average velocity and lower amplitude of oscillation of the PCP than non-athletes.

Material and methods

Participants

The study included 64 volunteers (33 men and 31 women), of whom 35 were volleyball players under the age of 21 (18.93 years ± 0.77) who had practiced the sport for at least two years; 29 were non-athletes (20.7 years ± 1.17). In the group of athletes, 18 had had at least one episode of sprain and, in the group of non-athletes, 16 had already had such an injury. The inclusion criteria comprised volunteers who presented sprain in at least one ankle, regardless of the severity of the injury. The exclusion criteria comprised individuals who were unable

to complete at least one of the tests, as well as those who had other injuries in lower limbs and trunk, neurological injuries, and acute sprains that hindered evaluations.

The study was approved by the Ethics Committee of the Federal University of São Paulo. All volunteers signed a free and informed consent form. Data collection was conducted in the laboratory.

Study design

The volunteers were subjected to static assessments (four tests) and dynamic (one). All tests were done in the unipedal stance on the MatScan System baropodometer, version 6.60 (Teckscan Inc., Boston, MA, United States) with the following dimensions: 620 mm × 645 mm, scanning speed of 100 Hz, and 8-bit pressure digital resolution for the analysis of the lower limb (LL) with worse severity sprain for volunteers who suffered sprains; for volunteers without sprain, the LL was drawn regardless of dominance. The system was calibrated for the weight of participant and according to the manufacturer's protocol.

The duration of each test was 10 s,[6] with a 20-s interval between them. The angles were measured by a universal goniometer. Volunteers performed three attempts for each test; only the data from the first complete attempt were considered. The order of tests was randomized by drawing envelopes that contained one of the five tests to be done.

Static evaluation. In the four static tests, the participant was required to remain barefoot, in the unipedal stance, on a baropodometer. The differences between tests comprised whether the eyes were open or closed, and whether the LL was stretched or flexed. Thus, the following tests were performed: Test 1, hip and knee extension and open eyes (OE); Test 2, hip and knee extension and closed eyes (CE); Test 3, hip at 30° and knee at 45° of flexion and OE; and Test 4, hip at 30° and knee at 45° of flexion and CE. Data collection in static testing was initiated at the evaluator's command and automatically completed at the end of 10 s.

Dynamic evaluation. The volunteer, barefoot, was required to perform a countermovement vertical jump and land on the baropodometer. In this case, the equipment automatically started collecting data only at landing and finished after 10 s.

The following variables were analyzed: area (cm^2), defined as the mean contact area (pressure points); distance (cm), defined as the distance between the peak plantar pressure points; anteroposterior oscillation (APO; cm), defined as the mean oscillation amplitude in the sagittal plane; mediolateral oscillation (cm), defined as the mean oscillation amplitude in the coronal plane; and mean velocity (MV; cm/s), calculated by dividing the distance by test duration. Data were collected with the SAM software, using the baropodometer extension program.

Prior to the baropodometer test, the items "Other symptoms"' and "Sport and recreation" from the subjective Foot and Ankle Outcome Score (FAOS) questionnaire were applied. In this questionnaire, higher scores mean subjectively better functional conditions. Although this factor is considered to be important by some authors,[15] hindfoot alignment (varus/valgus) was not measured in this study. There is still insufficient evidence as to the best measurement

methodology to be applied in clinical practice; since this study did not aim to compare the different methodologies, the authors chose not measure this variable.

Statistical analysis

The variables area, distance, *APO*, and mediolateral oscillation were analyzed, and the *MV* was calculated by dividing the distance by the test time. The variables of the static tests underwent 2 (knee: flexed or extended) × 2 (eye: open or closed) × 4 (group: athletes or non-athletes with and without sprain) analysis and an analysis of variance for repeated measures (ANOVA-RM). For the jump and the items of the FAOS questionnaire, multivariate ANOVA (MANOVA) was used among groups. *Post hoc* comparisons with Tukey's correction and partial eta square (η_P^2) were used as measures of the effect size.

For all statistical analyses, the significance level was set at 5% and SPSS (version 21) was used.

Results

Ten subjects were excluded (Fig. 1); therefore, the study included 54 assessments: 14 female athletes (11 sprains), 14 male athletes (seven sprains), 11 female non-athletes (seven sprains), and 15 male non-athletes (nine sprains).

ANOVA-RM revealed differences only for the variable distance, with major effects for eyes, $F(1,53) = 151.61$, $p < 0.001$, $\eta_P^2 = 0.75$; knee, $F(1,53) = 40.4$, $p < 0.001$, $\eta_P^2 = 0.45$; group, $F(1,53) = 15.59$, $p < 0.05$, $\eta_P^2 = 0.24$; and knee–eye interaction, $F(1,53) = 7.69$, $p < 0.05$, $\eta_P^2 = 0.13$. For the *MV* variable, the main effects were observed for eyes, $F(1,53) = 151.58$, $p < 0.001$, $\eta_P^2 = 0.75$; knee, $F(1,53) = 40.4$, $p < 0.001$, $\eta_P^2 = 0.45$; group, $F(1,53) = 5.2$, $p < 0.05$, $\eta_P^2 = 0.24$; and knee-eye interaction, $F(1,53) = 7.72$, $p < 0.05$, $\eta_P^2 = 0.13$. *Post hoc* analyses for both variables showed differences between athletes without sprain and both groups of non-athletes, with higher values for the former. MANOVA dynamic test indicated important group effects for the variables distance, $F(1,53) = 14.84$, $p < 0.05$, $\eta_P^2 = 0.23$; APO, $F(1,53) = 9.47$, $p < 0.05$, $\eta_P^2 = 0.16$; and MV, $F(1,53) = 9.95$, $p < 0.05$, $\eta_P^2 = 0.23$. *Post hoc* analyses for MV and distance indicated differences between athletes without sprain and the other groups; in turn, for the APO variable, differences were observed only between both groups of athletes (Tables 1–3).

Individuals without sprain had higher score on the FAOS questionnaire items when compared with those with sprains. However, MANOVA revealed no statistically significant differences ("Other symptoms": $F(1,53) = 2.74$, $p > 0.05$, $\eta_P^2 = 0.141$; "Sport and recreation": $F(1,53) = 1.48$, $p > 0.05$, $\eta_P^2 = 0.082$; Table 4).

Discussion

This study aimed to investigate, based on PCP oscillations, the postural control of athletes and non-athletes with and without sprain. To this end, the volunteers completed the tasks of standing in the unipedal stance and jumping and landing in the unipedal stance with open/closed eyes and extended/flexed knee. Considering previous studies,[2,3,6] the
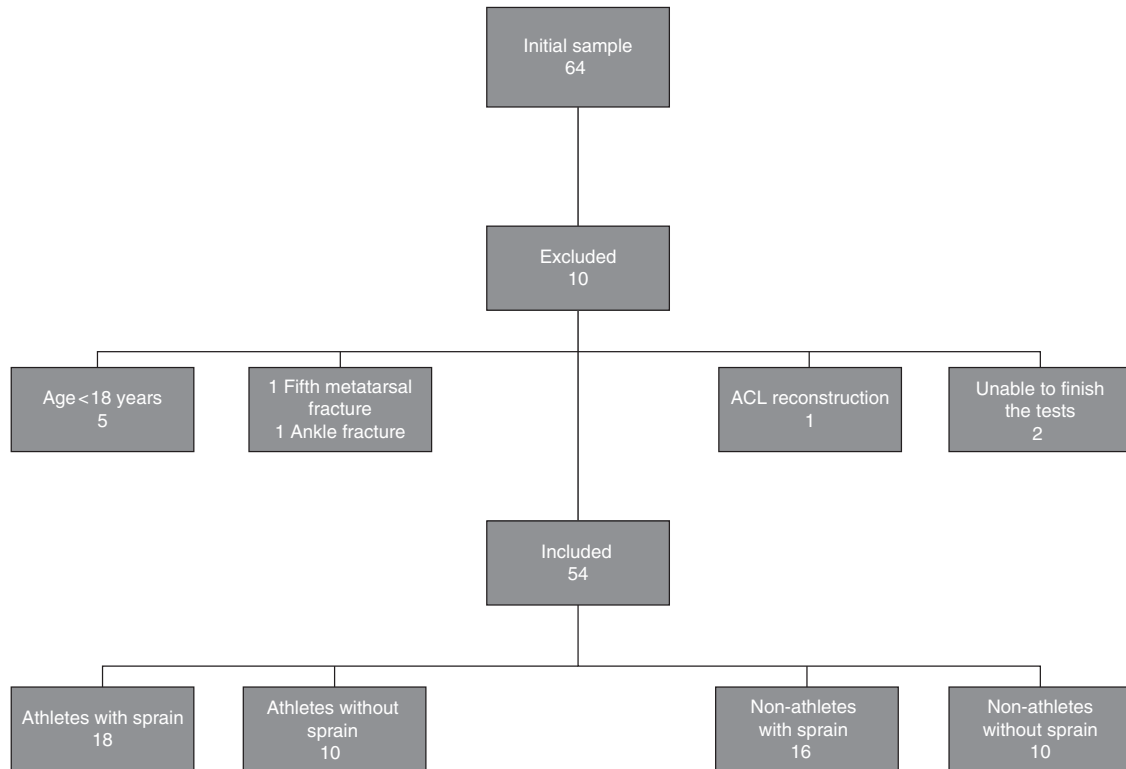
Fig. 1 – Flowchart showing the initial and final study sample. gr1.

Table 1 – Variables from the static test.

	Area (cm^2)			
	Athletes with sprain	Athletes without sprain	Non-athletes with sprain	Non-athletes without sprain
EOEK	7.72 (±4.9)	9.91 (±7.14)	5.3 (±4.05)	4.2 (±2.27)
EOFK	7.52 (±6.12)	10 (±5.36)	7.44 (±3.2)	5.57 (±3.3)
ECEK	18.52 (±12.62)	27.46 (±15.95)	15.99 (±5.73)	13.11 (±3.79)
ECFK	29.21 (±31.96)	33.78 (±24.08)	21.35 (±11.94)	31.34 (±25.74)
Distance (cm)				
EOEK	58.45 (±27.31)	89.44 (±54.05)[a,b]	48.16 (±16.39)[a]	40.17 (±11.85)[b]
EOFK	65.04 (±27.95)	103.29 (±55.01)	59.18 (±11.43)	51.11 (±14.53)
ECEK	104.25 (±49.87)	155.48 (±78.83)	94.58 (±24.94)	74.56 (±15.58)
ECFK	138.05 (±70.22)	170.68 (±90.74)	114.71 (±30.51)	130.74 (±62.72)
Anteroposterior oscillation (cm)				
EOEK	4.19 (±1.67)	5.1 (±2.42)	3.29 (±1.41)	2.91 (±0.82)
EOFK	3.84 (±1.9)	4.91 (±1.8)	4.24 (±1.34)	3.59 (±0.99)
ECEK	7.04 (±3.59)	9.83 (±5.12)	7.45 (±3.62)	5.51 (±1.13)
ECFK	8.18 (±4.39)	10.25 (±5.32)	7.84 (±3.02)	8.73 (±4.11)
Mediolateral oscillation (cm)				
EOEK	3.2 (±0.78)	3.31 (±1)	2.6 (±0.84)	2.58 (±0.81)
EOFK	3.36 (±1.22)	3.81 (±0.96)	3.07 (±0.77)	2.89 (±0.96)
ECEK	4.72 (±1.05)	5.04 (±1.29)	4.34 (±1.55)	4.22 (±0.71)
ECFK	5.9 (±2.8)	5.71 (±2.12)	4.84 (±1.06)	6.25 (±3.61)

Mean (standard deviation) of the distance variable.
EOEK, eyes open, extended knee; EOFK, eyes open, flexed knee; ECEK, eyes closed, extended knee; ECFK, eyes closed, flexed knee.

[a] Statistically significant ($p < 0.05$).
[b] Statistically significant ($p < 0.05$).

Table 2 – Variables from the dynamic test.

	Athletes with sprain	Athletes without sprain	Non-athletes with sprain	Non-athletes without sprain
Area (cm^2)	23.02 (±10.54)	30.9 (±24.37)	24.07 (±22.02)	17.41 (±7.1)
Distance (cm)	90.61 (±27.37)[a]	122.78 (±52.1)[a,b,c]	88.85 (±18.79)[b]	72.93 (±15.76)[c]
AP oscillation (cm)	13.24 (±3.8)	14.36 (±3.64)[b]	13.71 (±3.24)	10.11 (±2.66)[b]
ML oscillation (cm)	4.5 (±0.68)	5.36 (±1.69)	4.95 (±2.28)	4.31 (±0.99)

Mean (standard deviation) of the jump variable.
[a] Statistically significant ($p < 0.05$).
[b] Statistically significant ($p < 0.05$).
[c] Statistically significant ($p < 0.05$).

Table 3 – Mean velocity (cm/s).

	Athletes with sprain	Athletes without sprain	Non-athletes with sprain	Non-athletes without sprain
EOEK	5.85 (±2.73)	8.95 (±5.4)[b,c]	4.82 (±1.64)[b]	4.02 (±1.19)[c]
EOFK	6.5 (±2.8)	10.33 (±5.5)[b,c]	5.92 (±1.14)[b]	5.11 (±1.45)[c]
ECEK	10.43 (±4.99)	15.55 (±7.88)[b,c]	9.46 (±2.5)[b]	7.45 (±1.55)[c]
ECFK	13.81 (±7.02)	17.07 (±9.07)[b,c]	11.47 (±3.05)[b]	10.33 (±2.99)[c]
Jump	90.61 (±27.37)[a]	122.78 (±52.1)[a,b,c]	88.85 (±18.79)[b]	72.93 (±15.76)[c]

Mean (standard deviation) of the mean velocity variable.
EOEK, eyes open, extended knee; EOFK, eyes open, flexed knee; ECEK, eyes closed, extended knee; ECFK, eyes closed, flexed knee.
[a] Statistically significant ($p < 0.05$).
[b] Statistically significant ($p < 0.05$).
[c] Statistically significant ($p < 0.05$).

main hypothesis of the present study was that athletes, especially those without sprain, would present higher MV and less PCP oscillation when compared with non-athletes.

This hypothesis was partially confirmed. The results of static and dynamic tests demonstrated greater MV for the group of athletes without sprain when compared with athletes with sprains and both groups of non-athletes. This increase can be explained by SR principle. As previously mentioned, SR can be understood as the ability of sensory noise to potentiate subthreshold sensoriomotor signals in a given stimulated region and allow for an increased threshold, which in turn leads to their detection and consequent response to afferent activity, in this case, contraction.[13] Kuczyñski et al.[12] also observed higher PCP MV in second-division volleyball players when compared with non-athletes. These authors suggested that higher MV in athletes corresponds to better postural control, possibly as a result of the training routine,[6,9] which requires a constantly high level of neuromuscular control (high frequency of neural firings) due to the exposure to danger. In the present study, the MV increase in athletes without sprain can be explained by their increased neuromuscular control level from training, which, in line with the SR principle, may indicate that highly trainable athletes apparently have the ability to potentiate subthreshold sensoriomotor signals,

and therefore increase the activation threshold and the contraction response. The group of athletes with sprains did not present a higher MV than the group of non-athletes. This indicates that the injury may cause a possible decrease in this capacity due to the possible neural deficits that an ankle sprain can cause.

Contrary to our expectations, the group of athletes without sprain also showed greater PCP oscillation, considering the distance variable from the groups of non-athletes in the static and jump tests and higher APO when compared with the jump test of non-athletes without sprain. Again, the study by Kuczyñski et al.[12] corroborates the present results, as they observed a greater oscillatory amplitude, specifically in the sagittal plane, in volleyball players. These authors explain their results from the skill level of the athletes studied. The volunteers in the study by Kuczyñski et al.[12] were second-division athletes. This indicates that, although these athletes already presented SR muscle capacity, they were possibly still developing this ability and therefore did not yet have full control. Consequently, the lack of control reflects a larger oscillation amplitude, especially in relation to the distance variable, which is more sensitive as it is calculated by the distance between the peak plantar pressure points. In the present study, the athletes presented a skill level similar to

Table 4 – Items "Other symptoms" and "Sport and recreation" of the FAOS questionnaire.

	Athletes with sprain	Athletes without sprain	Non-athletes with sprain	Non-athletes without sprain
Other symptoms	81.35 (±3.19)	90.36 (±4.28)	86.6 (±3.39)	96.07 (±4.28)
Sport and recreation	85.83 (±3.78)	84.5 (±5.08)	91.87 (±4.01)	97 (±5.08)

Mean (standard deviation) of the scores of the items of the FAOS questionnaire.

second-division volleyball players; therefore, it can be argued that these athletes have the SR ability, but are still developing its control.

The study by Ross and Guskiewicz[7] found no differences in the range of APO and mediolateral oscillation among individuals with stable and unstable ankle. Nonetheless, individuals with instability took longer to become stable. This study corroborates the amplitudes of oscillations, but the time for stabilization was not measured due to equipment limitations.

Despite the higher MV and distance in athletes without sprain, the other variables showed no differences among the groups. These findings corroborate those by Kuczyñski et al.,[12] suggesting that the oscillatory amplitude is not determinant for MV increase, while the distance appears to be important, especially in dynamic situations.

Additionally, the results showed that vision and proprioception are important in maintaining the posture.[16,17] The integration of afferent/efferent information to maintain posture and balance results in intermittent muscle synergism,[18] causing a fluctuating PCP pattern.[19,20] The deficiency of one or both may compromise its maintenance.[16,17] In this study, the closed eyes and landing tests aimed to simulate volleyball situations in which the visual focus is not on the landing site. Under these conditions, floating standards were observed in all volunteers, corroborating the results of other studies.[19,20] Interestingly, these patterns were not associated with being an athlete or not.

Individuals without sprain scored higher on the items "Other symptoms" and "Sport and recreation" of the FAOS questionnaire when compared with those with sprains. However, there was no statistically significant difference, which pointed only to a trend. As this is a subjective questionnaire, the results can be justified by the fact that all volunteers continued to perform their activities as usual, regardless of injury history.

The results of this study indicate that athletes without sprain have higher MV of PCP oscillation, probably influenced by the SR principle, while athletes with sprain, despite having the same training routine, appear to have less influence due to the injury history and possible neural deficits resulting from sprains. In addition, second-division athletes have greater oscillation, specifically in the variable of distance. This potentially indicates that they are still developing this ability.

The high variability of the data collected may be due to differences in equipment and the small sample sized. These can be seen as limitations of the present study. In this study, a resistive baropodometer was used, while other studies canonically used force platforms. Despite the high reliability of force platforms, high cost prevents their popularization in clinical practice. Nonetheless, the resistive baropodometer appears to be useful in clinical practice, as it provides relevant and robust data, and it is an inexpensive option to the force platform.

Conclusion

Athletes have higher mean velocity of plantar center of pressure oscillation and do not have, in general, differences in the oscillation amplitude in the sagittal and coronal planes when compared with non-athletes.

Conflicts of interest

The authors declare no conflicts of interest.

Acknowledgements

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