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Kinematic adjustments of the ankle joint complex on different unstable surfaces

Ajustes cinemáticos do complexo articular do tornozelo sobre diferentes superfícies instáveis

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RESUMO | INTRODUÇÃO: Poucos estudos discutem as reações corporais de indivíduos saudáveis no momento em que os exercícios em superfícies instáveis estão sendo executados, embora os efeitos do treinamento – efeitos crônicos do exercício- sejam bastante estudados. **OBJETIVO:** Descrever a cinemática articular do tornozelo e retropé durante essa interação. **METODOLOGIA:** Dezoito voluntários participaram do estudo. A posição articular da região do tornozelo foi estudada em três superfícies: AIREX® Balance-pad, BOSU® e chão (controle). Para análise estatística, utilizou-se ANOVA e Pós-teste de Tuckey, considerando um nível de significância menor que 0,05. **RESULTADOS:** A posição articular da região tornozelo no plano sagital foi diferente no BOSU® em relação ao AIREX® ($p < 0.001$) e ao chão ($p < 0.001$). O tornozelo ficou em posição mais próxima à neutra no AIREX® e no chão. Com o BOSU, a dorsiflexão foi acentuada. Não houve diferença da posição média no no plano frontal. A variabilidade da posição da região do tornozelo foi maior no BOSU® que no AIREX® ($p < 0.001$) e no chão ($p < 0.001$), tanto no plano sagital, quanto no plano frontal. A frequência média de deslocamento da posição articular na região do tornozelo no plano sagital foi maior no BOSU® que no chão ($p < 0.001$); e no plano frontal, para o retropé, foi maior no BOSU® que no AIREX® ($p < 0.001$) e chão ($p < 0.001$). **CONCLUSÃO:** Houve diferença no comportamento articular da região do tornozelo na condição BOSU® em relação às demais nas superfícies utilizadas, havendo um aumento das oscilações articulares no processo de controle postural em condições mais instáveis e maior dosiflexão no BOSU®.

PALAVRAS-CHAVE: Equilíbrio. Superfícies instáveis. Eletrogoniometria. Tornozelo.

ABSTRACT | INTRODUCTION: There are few studies approaching the bodily reactions of healthy individuals while performing exercises on unstable surfaces although the training effects – exercise chronic effects - are well studied. **OBJECTIVE:** The goal of this study was to describe the ankle and rear foot region osteoarticular kinematic during these interaction. **METHOD:** Eighteen volunteers participated in the study. The ankle joint displacement was studied in three different surfaces: AIREX® Balance-pad, BOSU® and Ground (control). Statistical analysis was performed using ANOVA and Tukey test, considering a significance level of 0.05. **RESULTS:** The position of the ankle joint in the sagittal plane was greater in the BOSU® than in the AIREX® ($p < 0.001$) and ground ($p < 0.001$). The ankle was close to the neutral position in the AIREX® and on the ground. With BOSU, the dorsiflexion was increased. Considering the frontal plane, there was no difference in the rear foot position. Moreover, the variability in the ankle mobility in sagittal and frontal planes was higher in BOSU® than AIREX® ($p < 0.001$) and ground ($p < 0.001$). The mean frequency of the ankle position in the sagittal plane was greater in the BOSU® than on the ground ($p < 0.001$), and, in frontal plane, the rear foot frequency displacement was largest in the BOSU® than in the AIREX® ($p < 0.001$) and on the ground ($p < 0.001$). **CONCLUSION:** There were observed differences in ankle postural control strategies in the BOSU® condition when compared with the other surfaces tested. The ankle and rear foot oscillations increase and there is a greater dorsiflexion for the postural control under the most unstable condition - BOSU.

KEYWORDS: Balance. Unstable surfaces. Electrogoniometry. Ankle.

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Introduction

There is a wide literature reporting a frequent use of unstable surfaces in different populations, with the aim of treating orthopedic or neurological patients by using several devices that generate different degrees of instability. These devices are intended to increase the complexity of the motor task, and lead to greater challenges to postural control[1-12]. However, most of the scientific studies on this subject compare the parameters of interest before and after training, inferring about the chronic effects of the training[13-19].

These studies usually evaluate the muscle recruitment patterns related to postural adjustments and postural balance after training, including the use of unstable surfaces[13-19]. However, actions and body reactions induced by the interaction of individuals with unstable surfaces - that is, the acute effects of these exercises - have been studied in the last 3 decades[1-12, 20]. In these studies, the displacement of center of pressure, the electromyography signal of the leg muscles and the amplitude of movement of the ankle joint are monitored while the exercise is performed.

A recent study by Strom et al. (2016)[12] was the first to evaluate parameters such as the peak velocity of ankle region movement and the number of inversions and eversions during single-legged balance on unstable surfaces[12]. In turn, Farias et al. (2016)[3], propose to evaluate cardiorespiratory parameters and emotional valences while standing on unstable surfaces. However, the literature lacks studies that evaluate how the ankle joint moves in amplitude and frequency, wich are important parameters to describe postural strategies for the control of postural balance.

Therefore, the present study aimed to evaluate the joint kinematics while maintaining the bipedal postural stance on different unstable surfaces by means the temporal series of the ankle joint movement.

The specific goals were to measure the mean position, the position standard deviation, and the frequency content of the temporal series of the ankle joint movement on two multidirectional unstable surfaces, considering the ground as a control (stable surface).

Our hypothesis was that dorsiflexion, the standard deviation and the frequency content increase with increasing instability. Dorsiflexion would project the center of gravity forward, making the activity execution safer under more unstable conditions. The standard deviation and frequency content increase would be a result of the greater joint excursion and the demand for faster adjustments in high instability situations.

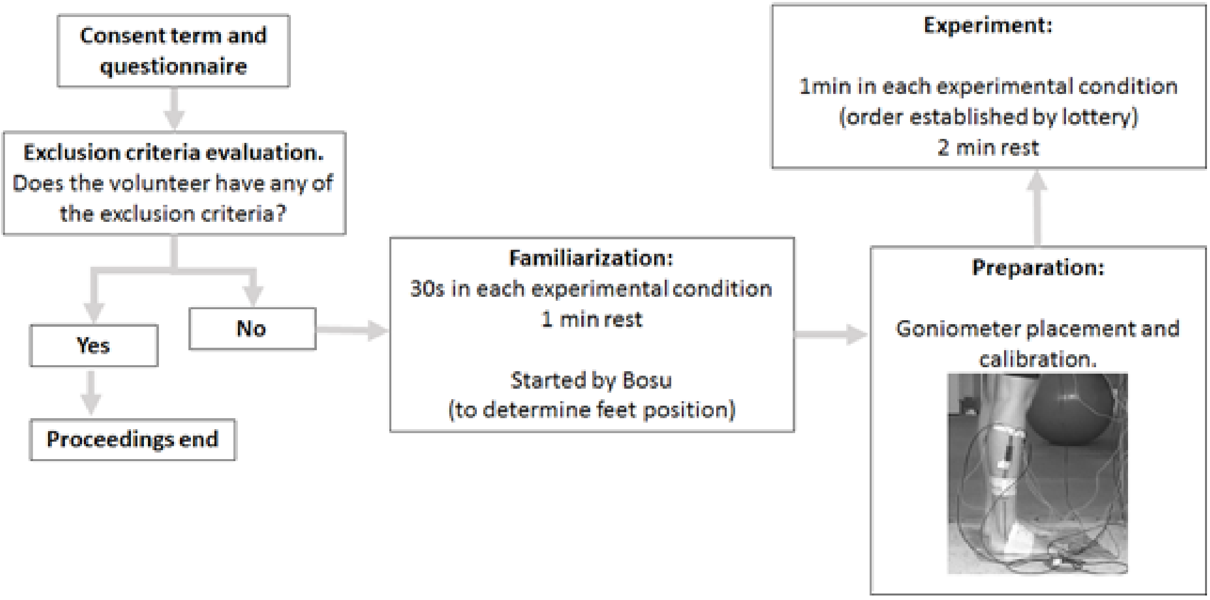
Methods

This study was based on a kinematical analysis of the ankle joint in two different conditions of multidirectional postural instability.

The procedure took place in the Laboratory of Corporeity of the Federal Institute of Education, Science and Technology of Rio de Janeiro - Campus Realengo. The sample was obtained by convenience and the entire procedure was done in a single day. The procedure lasted approximately 15 to 20 min for each volunteer. The exclusion criteria were: severe cardiorespiratory diseases, visual or vestibular dysfunctions, important ankle, knee, hip and spine pain. All the volunteers were informed of the research objectives and procedures and signed an informed consent form. The study approved (CAAE: 08305013.0.0000.5268) by the Research Ethics Committee.

After the exclusion criteria evaluation, eighteen healthy volunteers (sixteen women), between 18 and 53 years old, height between 152 and 180 cm, body mass between 43 and 109 kg and BMI between 18.61 and 33.64 kg/m2 participated in the study. The volunteers performed the following steps: familiarization with the protocol and the unstable surfaces; data acquisition preparation, and the test, performed on three experimental conditions (AIREX® Balance-pad, BOSU® and Stable Ground), as shown in the diagram below (Figure 1):

Figure 1. Experimental protocol diagram



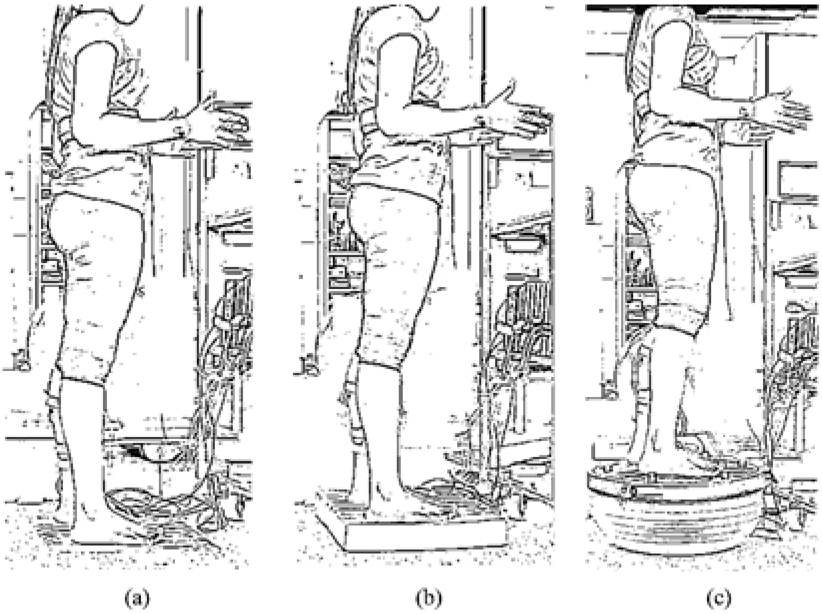
Familiarization was done to determine the most appropriate foot position to perform the exercises, and to familiarize the volunteer with the test. The volunteer should keep a comfortable orthostatic position on each experimental condition, with a fixed point at eye level positioned three meters away, arms alongside the body, elbows flexed at 90°, forearm in neutral position, and thumbs facing up. That upper limb position facilitates to support on an aid device located in front of the volunteer, to be used in case of imminent fall. During the familiarization, the task duration on each of the surfaces was 30 seconds, with 1-minute interval between the conditions. The position of the feet was established as a comfortable position during the experimental condition considered more challenging (BOSU®), thus, BOSU® was the first unstable surface used during the familiarization stage by all volunteers.

After the familiarization stage, a biaxial digital electrogoniometer (BIOPAC Systems Inc, 2012) was positioned on the lateral side of the dominant leg. One extremity of the electrogoniometer was fixed vertically to the leg and the other attached following the length of the foot horizontally, passing through the ankle joint[21], making it possible to acquire the angular positions of the ankle and rear regions in the sagittal and frontal planes. In this paper, the term ankle joint complex was used to indicate the following regions: the ankle and subtalar joints and adjacencies, where the goniometer sensor was fixed on, allowing the reference to the movements in the frontal plane. The electrogoniometer calibrations were performed for each volunteer, before the tests, according to the MP System Hardware Guide (BIOPAC Systems Inc, 2014)[22].

The experiment consisted in maintaining the posture described in the familiarization step on three types of surfaces: stable Ground (control situation), inverted BOSU® (flat base up) and AIREX® Balance-pad (Figure 2). Both unstable surfaces used in this experiment provide multidirectional instability. Each exercise lasted one minute on each surface and a rest period of 2 minutes between the experimental tasks. The order of the surfaces was randomized.

The methods adopted in the familiarization and the position of the volunteer during the experiment were similar to those adopted by Farias et al. (2016)[3].

Figure 2. Posture adopted during the experiment for Ground (a), AIREX® Balance-pad (b) e BOSU® (c) conditions


(a) (b) (c)

The lectrogoniometer signals were amplified and filtered with anti-aliasing filter (10-750 Hz) and acquired simultaneously with a sampling frequency of 1000 Hz. The parameters analyzed from the time series register of the joint position in the sagittal (dorsiflexion / plantar flexion) and frontal (lateral movements) planes were: the joint mean position in each experimental task, the joint position variability (inferred from the standard deviation of the temporal series) and the joint position mean frequency, in the sagittal and frontal planes. These signals were processed Matlab® software, version 7.0. Statistica software version 7.0 was used for the statistical analysis of the data. The analysis of variance with repeated measures (one-way ANOVA) and post-hoc Tukey HSD test were performed, considering a significance level of 0,05.

Results

The ankle mean position in the sagittal plane was dorsiflexion (greater in the BOSU® than in the AIREX® Balance-pad ($p = 0.0003$) and on the Ground ($p = 0.0002$)). There was no difference between the AIREX® Balance-pad and the Ground ($p = 0.95$), where ankle was closer to the neutral (90°) position (Figure 3a). The ankle position variability magnitude in this plane was higher in the BOSU® than in the AIREX® Balance pad ($p = 0.0001$) and on the Ground ($p = 0.0001$). There was no significant difference ($p = 0.52$) between the AIREX® Balance-pad and the Ground (Figure 3b). The signal mean frequency of the ankle position displacement in the sagittal plane was higher on BOSU than on the Ground ($p = 0.0219$). There was no difference between BOSU® and AIREX® Balance-pad ($p = 0.6933$) and between AIREX® Balance-pad and Ground, $p = 0.13$ (Figure 3c).

There was no difference in the mean position of the ankle region between the three conditions in the frontal plane (Figure 4a). However, the ankle joint complex position variability amplitude was greater in the BOSU® than in the AIREX® Balance-pad ($p = 0.0013$) and on the Ground ($p = 0.0004$). There was no difference between the AIREX® Balance-pad and the Ground ($p = 0.70$) (Figure 4b). The mean frequency of the ankle joint complex movement was also higher on BOSU® than in the AIREX® Balance-pad ($p = 0.0380$) and on the Ground ($p = 0.0122$). There was no difference between the AIREX® Balance-pad and the Ground, $p = 0.80$ (Figure 4c).

Figure 3. Mean position (a), ankle position variability (b) and mean frequency (c) for sagittal plane during AIREX® Balance-pad, BOSU® e Ground (control) experimental conditions. For mean position, 90° is considered the neutral posture (higher values indicate plantar flexion and lower values indicate dorsiflexion)

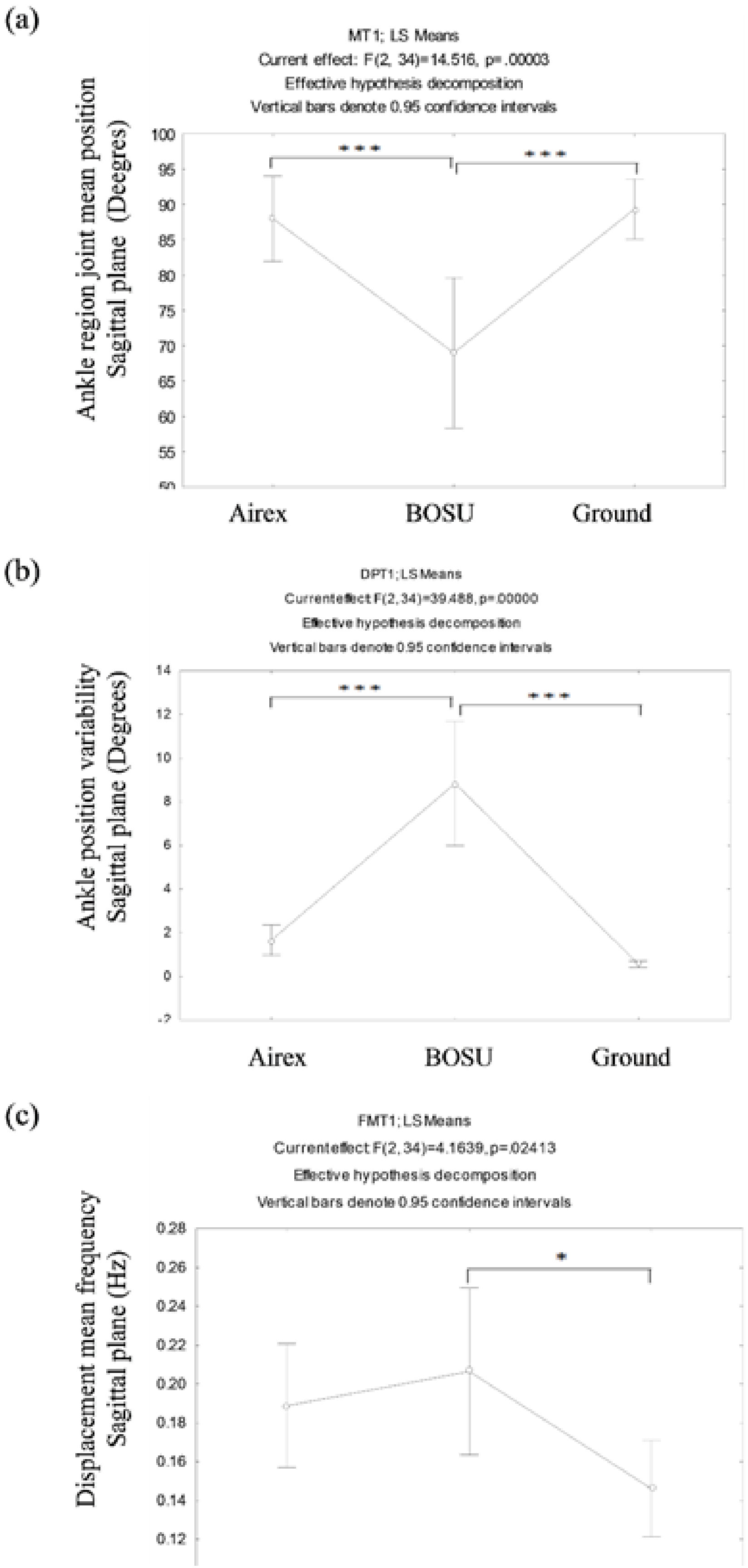
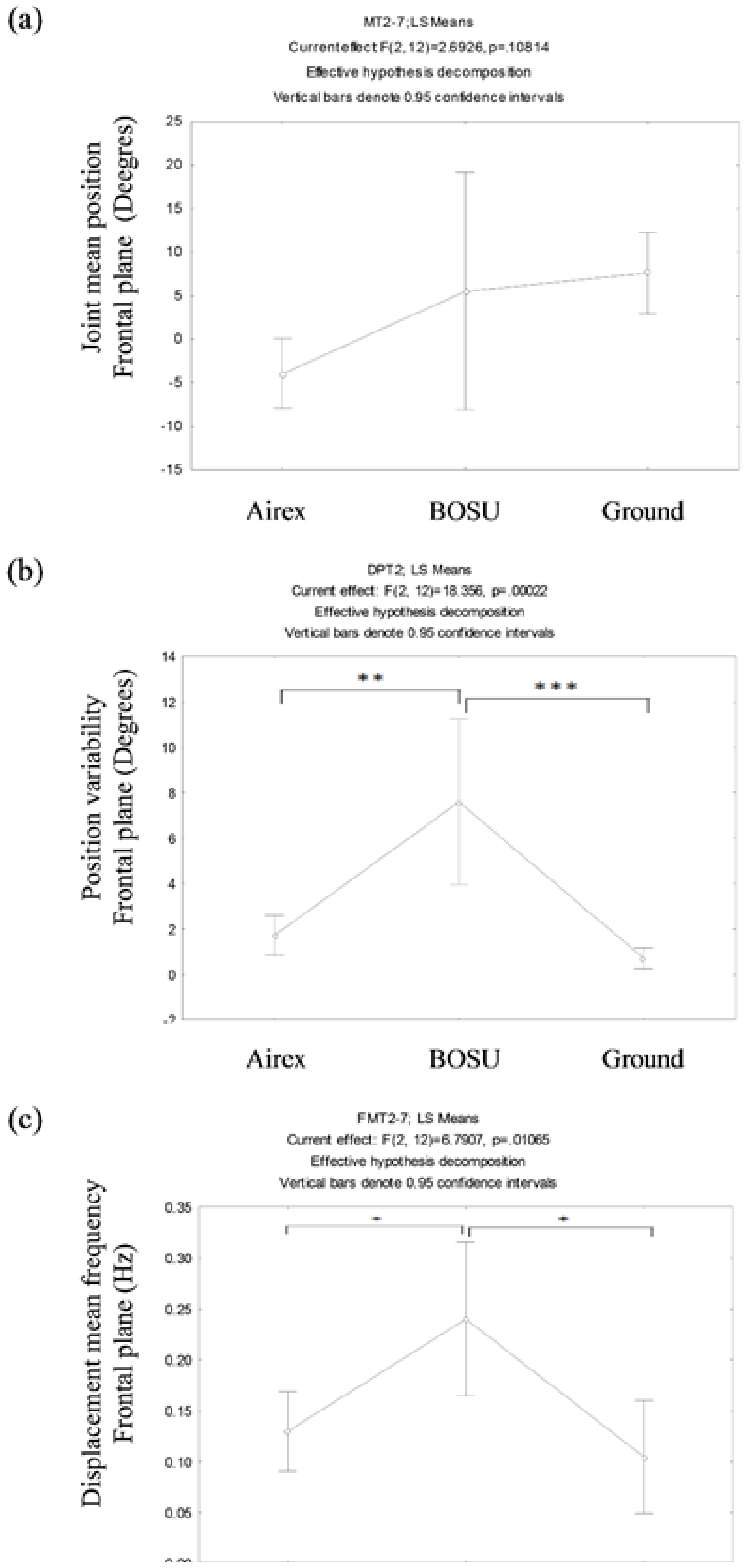


Figure 4. Mean position (a), position variability of the ankle region joints (b) and mean frequency (c) for frontal plane during AIREX® Balance-pad, BOSU® e Ground (control) experimental conditions. For mean position, positive values indicate inversion and negative values indicate eversion



Discussion

This study aimed to verify the behavior of the ankle joint complex during exercises on two unstable multidirectional surfaces (AIREX® and BOSU®), using the floor as control.

The muscle activity of healthy individuals on unstable surfaces is explored in the literature[1, 2, 4-10]. Some authors have studied the range of motion of the ankle joint complex on unstable surfaces. However, we did not find studies that evaluated the joint mean position and the frequency content of movement of the ankle joint complex on unstable surfaces, considering two-legged stance, which is the main contribution of this study. Such parameters provide information regarding the kinematics of the ankle joint complex in activities that do not require great range of motion. Such parameters provide information about variations in the position of the ankle joint complex in activities that do not require extreme articular range of motion. Thus, these data give us a clue about control strategies adopted in these motor tasks, and how the ankle joint complex move on.

Recently, Strom et al. (2016)[12] published a paper evaluating the variability of the ankle joint complex movement, peak inversion and changes in direction of inversion and eversion movements. The authors, as well as in this study, used AIREX® and BOSU®. Additionall they used the wobble board. However, they evaluated the exercises in one-legged stance and, consequently, they focused their evaluations to the inversion and eversion movements.

Our findings corroborate our hypotheses and suggest more pronounced dorsiflexion posture of the ankle region in the BOSU®, the most unstable surface we used. The ankle posture remained closer to the neutral position (90°) in AIREX® and on the Ground. The mean frequency of the ankle position displacement in the sagittal plane was greater on BOSU® than on the Ground. In the frontal plane, the frequency content of the ankle joint complex was higher on BOSU® than on AIREX® and the Ground. These results possibly suggest an anterior body displacement associated to an increase in magnitude and frequency of the oscillations in the postural control process under more unstable conditions. The conduted by Strom et al. (2016)[12] study was performed in one-legged stance that intensifies lateral oscillations, and they found a greater lateral oscillations on BOSU® than on the Ground and AIREX®. Our protocol was performed in two-legged stance, where lateral oscillations decrease and we did not find significant differences for mean position amplitude in frontal plane, but an increase frequency in frontal plane on BOSU® condition was observed, indicating a sensitive parameter that infers on the speed of the variations in situation of smaller oscillation as is the case of the two-legged compared with one-legged stance.

Horstmann, Mündermann and Rapp (2015)[6] and Ivanenko et al. (1997)[7] studied healthy individuals were they analyzed leg muscles activity and ankle joint complex amplitudes during experimental tasks on unstable surfaces. Horstmann, Mündermann and Rapp (2015)[6] used a balance pad and two parallelepiped surfaces and observed no difference in ankle joint complex amplitudes variation between the surfaces. Ivanenko et al. (1997)[7] used small seesaws of different radii and heights to produce movements in the sagittal plane[7]. The wider the radius and the smallest the height, more stable the surface. In the more unstable surface, the joint amplitude in the sagittal plane was 3 to 10 times greater than in more stable one. This increase corroborates our findings, when BOSU® was compared with the other surfaces. Horstmann, Mündermann and Rapp (2015)[6] may have found no difference because they used less challenging surfaces. It is noteworthy that in our study we also did not find significant differences in joint behavior between AIREX® (a less challenge surface than BOSU®) and the Ground.

Other studies using stabilometric parameters point out that the greater the degree of instability provided by the surface, the greater the body displacement[1, 2, 11]. Considering these experiments, the Stanek, Meyer and Lynall (2013)[11] protocol used the AIREX® and the BOSU®, as we did, and also a half-foam roller and the DynaDisc®. However, they analyzed one-legged stance condition. They found significant differences for area of the center of pressure (CP) and oscillation mean velocity between BOSU® and the other 3 devices.

Study limitations: We did not observe the trunk, hip and knee joints and we did not analyze muscular activity. The kinematics of the ankle joint complex and the associated muscular activation are important to understand corporal strategies used for postural control on unstable surfaces. The results address the ankle region and two specific multidirectional unstable surfaces and no generalization can be made for other areas or for other types of unstable surfaces. Studies comparing body strategies on different unidirectional and multidirectional surfaces, as well as the challenge imposed by different levels of exercise, are necessary for better understand ing body dynamics in different conditions and to guide the exercise progression prescription. Nevertheless, we believe that our results contribute to understand the ankle region joints behavior on the unstable surfaces used.

Conclusion

The magnitude and frequency content of the ankle joint complex were higher on the BOSU®, the most unstable surface. There was an increase in ankle dorsiflexion, while in other surfaces the position remained closer to the neutral position. The variability magnitude increased in both planes with the BOSU. The mean frequency of the ankle region position displacement increased in the frontal plane with the BOSU® and in the sagittal plane when BOSU® and the Ground are compared. Our results suggest important changes in the strategies for the postural control on unstable surfaces, through faster and more intense articular adjustments in the ankle oint complex in conditions of greater instability.

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Author contributions

Cruzeiro KA was responsible for the statistical analysis of the data and writing of the manuscript. Imbiriba LA was responsible for the study design, co-supervision of the research and writing of the manuscript. Farias S participated in the design, data collection and drafting of the manuscript. Rodrigues M was responsible for the study design and writing of the manuscript. Garcia M was responsible for the co-supervision of the research and writing of the manuscript. Donato C performed the data collection and analysis and writing of the manuscript. Macedo AR was responsible for the study design, supervision of the research work and writing of the manuscript.

Competing interests

No financial, legal or political competing interests with third parties (government, commercial, private foundation, etc.) were disclosed for any aspect of the submitted work (including but not limited to grants, data monitoring board, study design, manuscript preparation, statistical analysis, etc.).

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