HOSPITAL UNIVERSITÁRIO
HUPE
PEDRO ERNESTO

Artigo original

Immediate effects of whole-body vibration exercise on thermal symmetry of the lower legs and ankles

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Abstract

Introduction: Whole-body vibration exercise (WBV) has become an alternate modality of exercise for rehabilitation. Few studies have addressed the effect of this exercise modality using skin temperature as an outcome measure and fewer have studied the effect of whole-body vibration on thermal symmetry. The aim of this study is to evaluate the impact of acute exposure to vibration exercise on thermal symmetry of the lower legs in healthy subjects.
Methods: Skin temperature of 36 healthy and non-trained male and female subjects was recorded using thermography (FLIR A325sc camera), before and after the exposure to vibration exercise or control setting. All subjects were instructed to undress and remain still in the examination room for 15 minutes to achieve thermal stabilization. The room temperature and relative humidity were controlled, with absence of air flow. The Power Plate® provided mechanical stimulation with parameters set at a frequency of 35Hz, high amplitude (5-6mm), resulting in maximum acceleration of 121-145 m/s2, for 5 minutes.
Results: Thermal symmetry was higher in the anterior aspect of the lower leg (0.17±0.13ºC) and lower in the lateral aspect of the ankle (0.27±0.20ºC). The acute bout of exposure to WBV significantly affected thermal symmetry in both ankles, anterior and lateral aspects ($p \leq 0.05$).
Discussion: The results suggest that the exposure to an acute bout of vibration exercise (35Hz) influences thermal symmetry of the ankles, though the mechanism underlying these changes will require future studies to be fully understood either in healthy and patient subjects.

Keywords: Skin temperature; Thermography; Vibration.

Resumo

Efeitos imediatos do exercício de vibração de corpo inteiro na simetria térmica das pernas e tornozelos
Introdução: O exercício vibratório de corpo inteiro (WBV) tornou-se uma modalidade alternativa para exercício e reabilitação. Poucos estudos abordaram o efeito desta modalidade de exercício usando a temperatura da pele como medida de resultado e menos estudaram o efeito da vibração do corpo inteiro na simetria térmica. O objetivo deste estudo é avaliar o impacto da exposição aguda ao exercício de vibração na simetria térmica da parte inferior das pernas e tornozelos em indivíduos saudáveis.

Métodos: A temperatura da pele de 36 indivíduos saudáveis, não treinados, do sexo masculino e feminino, foi registada usando termografia (camara FLIR A325sc), antes e após a exposição ao exercício de vibração ou situação de controle. Todos os indivíduos foram instruídos a despir-se e a permanecer sala de exame por 15 minutos para alcançar a estabilização térmica. A temperatura ambiente e a humidade relativa foram controladas, com ausência de fluxo de ar. A Power Plate® forneceu uma estimulação mecânica com parametros definidos em uma frequência de 35 Hz, alta amplitude (5-6 mm), resultando numa aceleração máxima de 121-145 m/s^2, por 5 minutos.
Resultados: A simetria térmica foi maior na face anterior da perna (0,17±0,13ºC) e menor na região lateral do tornozelo (0,27±0,20ºC). A exposição aguda à WBV afetou significativamente a simetria térmica em ambos os tornozelos, nas faces anteriores e laterais ($p \leq 0,05$).
Discussão: Os resultados sugerem que a exposição a um exercício agudo de vibração (35Hz) influencia a simetria térmica dos tornozelos, embora o mecanismo subjacente a essas mudanças exija que estudos futuros sejam totalmente compreendidos em indivíduos saudáveis e pacientes.

Descritores: Temperatura da pele; Termografia; Vibração.

Resumen

Efectos inmediatos del ejercicio de vibración de todo el cuerpo sobre la simetría térmica de la parte

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Revista HUPE, Rio de Janeiro, 2018;17(1):22-29
doi: 10.12957/rhupe.2018.39272
Recebido em 12/07/2018. Aprovado em 25/10/2018.

inferior de las piernas y los tobillos

Introducción: el ejercicio de vibración de cuerpo entero (WBV) se ha convertido en una modalidad alternativa para el ejercicio y la rehabilitación. Pocos estudios han abordado el efecto de esta modalidad de ejercicio usando la temperatura de la piel como una medida de resultado y menos han estudiado el efecto de la vibración de todo el cuerpo sobre la simetría térmica. El objetivo de este estudio es evaluar el impacto de la exposición aguda al ejercicio de vibración en la simetría térmica de la parte inferior de las piernas y los tobillos en sujetos sanos.

Métodos: La temperatura de la piel de 36 sujetos masculinos y femeninos sanos y no entrenados se registró mediante termografía (cámara FLIR A325sc), antes y después de la exposición al ejercicio de vibración o al entorno de control. Todos los sujetos recibieron instrucciones de desvestirse, permanecieron quietos en la sala de examen durante 15 minutos para lograr la estabilización térmica. La temperatura ambiente y la humedad relativa se controlaron, con ausencia de flujo de aire. El Power Plate® proporcionó una estimulación mecánica con parámetros establecidos a una frecuencia de 35 Hz, alta amplitud (5-6 mm), lo que resulta en una aceleración máxima de 121-145 m/s2, durante 5 minutos.

Resultados: la simetría térmica fue mayor en la cara anterior de la parte inferior de la pierna (0.17±0.13°C) y más baja en el perfil lateral del tobillo (0.27±0.20°C). El episodio agudo de exposición a WBV afectó significativamente la simetría térmica en ambos tobillos, aspectos anterior y lateral (p≤0.05).

Discusión: Los resultados sugieren que la exposición a un ejercicio agudo de vibración (35 Hz) influye en la simetría térmica de los tobillos, aunque el mecanismo subyacente a estos cambios requerirá que los estudios futuros se entiendan completamente en sujetos sanos y pacientes.

Palabras clave: Temperatura de la piel; Termografía; Vibración.

Introduction

Exercise is one of the most common interventions in sport and rehabilitation settings. Vibration may be defined as a mechanical movement oscillating around a fixed point, transferring energy between the vibration generator and the surface it contacts with, e.g. the human body. Vibration produces waves and each wave may be characterized by frequency, acceleration, velocity and displacement.[1]

Vibration may be integrated in exercise, and the most common form of vibration exercise is whole-body vibration (WBV). This exercise modality is very popular[2] and its potential benefits as a complement to traditional exercise in many populations are well known[3]. Neurogenic potentiation involving spinal reflexes and muscle activation by tonic vibration reflex are amongst the proposed mechanisms for such benefits.[4] An increase in skin blood flow[5] and muscle perfusion[6] has been observed, suggesting vasodilation in the skin and vibrated musculature. To attenuate the effects of vibration, muscular activity increases, increasing the request for blood perfusion to comply with higher metabolic demands.

The skin is the natural interface between the environment and the inner body and is a key element in thermoregulation. Skin temperature (TSk) is influenced by the complex relationship characterizing heat exchange between the skin and the environment.[7] Depending on the situation, the skin may behave as a radiator or as insulator of heat. Cutaneous blood flow is controlled by the sympathetic nervous system through vasodilation and vasoconstriction mechanisms whenever it is necessary loose or maintain heat in the body, respectively.[8, 9] The balance between heat production through metabolism or exercise and heat dissipation through convection, conduction and evaporation determines TSk. This parameter may be assessed using different methodologies, such as thermistors, infrared thermometers, temperature probes and thermal imaging. Thermal imaging is a non-invasive, non-ionizing, radiation emission free imaging modality, able to measure TSk without contact, therefore not influencing it. The method has been validated and its application scope is large.[10, 11] The degree of similarity between the temperature of two regions of interest (ROI) mirrored across the human body longitudinal axis has been described as thermal symmetry[12] and my be used to quantify the response to training.[13]

The effects of WBV on peripheral circulation are not well documented. This issue has been approached using different outcomes such as intramuscular temperature,[14] laser doppler,[5] ultrasound[6] and skin temperature[15] and the results were heterogenous, highlighting the complexity of the topic. Considering the effects of WBV on skin temperature using thermal imaging in the assessment, few studies have used this outcome. Games and Sefton,[16] Seixas and collaborators,[17, 18] and Sonza et al.[19] have all described the effects of WBV on TSk, some reporting an increase[16] and others reporting a decrease in TSk.[17-19] However, the effects of WBV in thermal symmetry are poorly explored and only one study reported that WBV affected thermal symmetry, increasing side to side temperature differences.[17] However, these results need further verification to confirm or refute this finding.

Therefore, the goal of this research is to assess the immediate effects of WBV on thermal symmetry of the lower legs and ankles.

Materials and methods

Study Design

A randomized controlled trial, was conducted in a single session. The study was approved by the ethical committee of a local university and followed the recommendations of the Declaration of Helsinki. After the aims and the procedures of the study were explained, all participants signed the informed consent form to participate. Each participant reported to the laboratory in a single afternoon, in which two TSk assessments were performed, one before the experimental procedures and one after the experimental procedures.

Study Population

The eligibility criteria to participate were: aged between 18 and 25 years; absence of self-reported cardiovascular, neurologic, metabolic, or musculoskeletal disorders; not taking any medication affecting the previously mentioned systems. Thirty-six healthy and non-trained subjects recruited from the local university and meeting the eligibility criteria volunteered to participate and were randomly assigned stratifying by gender, using an online platform (http://www.randomization.com/), to one of the study groups, the experimental and control groups (Table 1). When asked to kick a ball, 97.2% of the participants used the right foot, suggesting it was the dominant limb.

Equipment

To assess TSk, a thermal camera (FLIR Systems, A325sc, Wilsonville, OR, USA), which has a sensor array size of 320x240, noise equivalent temperature difference (NETD) <50 mK and ± 2% of repeatability of the overall reading with emissivity set to 0.98. Thermograms were captured and analysed using the software FLIR ThermaCAM Researcher Pro 2.[10]

The mechanical stimulation of vertical synchronous vibration was provided by the Power Plate® (Performance Health Systems, Irvine, United States) with parameters set at a frequency of 35Hz, high amplitude (5-6 mm), resulting in maximum acceleration of 121-145 m/s^2.

Skin Temperature Assessment

The protocol for assessing TSk followed the guidelines for recording and reporting thermographic data,[20-22] Volunteers were instructed to refrain from smoking, drinking coffee, taking heavy meals, drinking alcohol or showering for at least two hours before data collection. The thermal camera was switched on for at least 30 minutes before data collection. Ambient temperature and relative humidity were controlled (22.45±0.56°C; 48.8±1.4%) and the assessment was made away from any source of infrared radiation or airflow. Thermograms were acquired after a 15-minute acclimation period with the camera positioned perpendicularly to the lower limbs at 2 metre distance. The ROI were defined in the anterior and posterior aspects of the lower legs and in the medial anterior and lateral aspect of the ankles of both lower limbs (Figure 1) in a total of 7 thermograms.

Thermal symmetry (ΔT) was computed as the absolute value of the side to side difference of the mean TSk in each ROI, before and after WBV exposure.

Whole-Body Vibration Protocol

Participants stood on the WBV platform with feet positioned at shoulder width and knees approximately at 45° of flexion. Participants were told to grip the safety handles lightly without resting their body weight on them, and feedback was provided to maintain the position. Volunteers were barefoot to diminish the attenuation of vibration by shoes. Non-slip foam was attached to the platform surface to reduce the risk of sliding. Participants in the experimental group

Table 1. Group characterization, Gender (M: males/ F: females), Age (years) and Body Mass Index (Kg/m^2)

Study Groups	n	Gender	Age	BMI
Experimental Group	18	9M / 9F	25.67±3.16	22.38±2.78
Control Group	18	9M / 9F	22.78±4.17	22.62±2.23

were exposed to WBV at a frequency of 35Hz, high amplitude (5-6 mm) for 5 minutes. Participants in the control group were equally positioned on the platform, at the same knee angle, for 5 minutes but without vibration.[17] These vibration parameters were chosen because WBV with higher frequencies (> 30Hz) has been associated with greater musculoskeletal power gains.[23] Moreover, since previous research has demonstrated similar effects in TSk using 35Hz and 40Hz (high amplitude) WBV exposure,[18] we opted to use 35Hz (high amplitude), in this study.

Statistical Analysis

All data analysis was performed using Statistical Package for the Social Sciences (SPSS Statistics, IBM, version 25) and STATISTICA (Dell, version 13). Data distribution was assessed with the Shapiro-Wilk test and since data followed a non-gaussian distribution, non-parametric tests were selected. To compare TSk values before and after WBV and to compare thermal symmetry values before and after the experimental protocol, the non-parametric Wilcoxon text was used and effect size was calculated using the formula: *Effect* $Z/\sqrt{N}$.[24] The 95% confidence intervals for the median differences were estimated using the Hodges-Lehman estimator. The agreement between the measures taken from the right and left foot, where significant differences in thermal symmetry were found, was assessed using the technique described by Bland and Altman,[25] assessing agreement and limits of agreement (average ± 1.96 standard deviation of differences). A post hoc analysis has been conducted

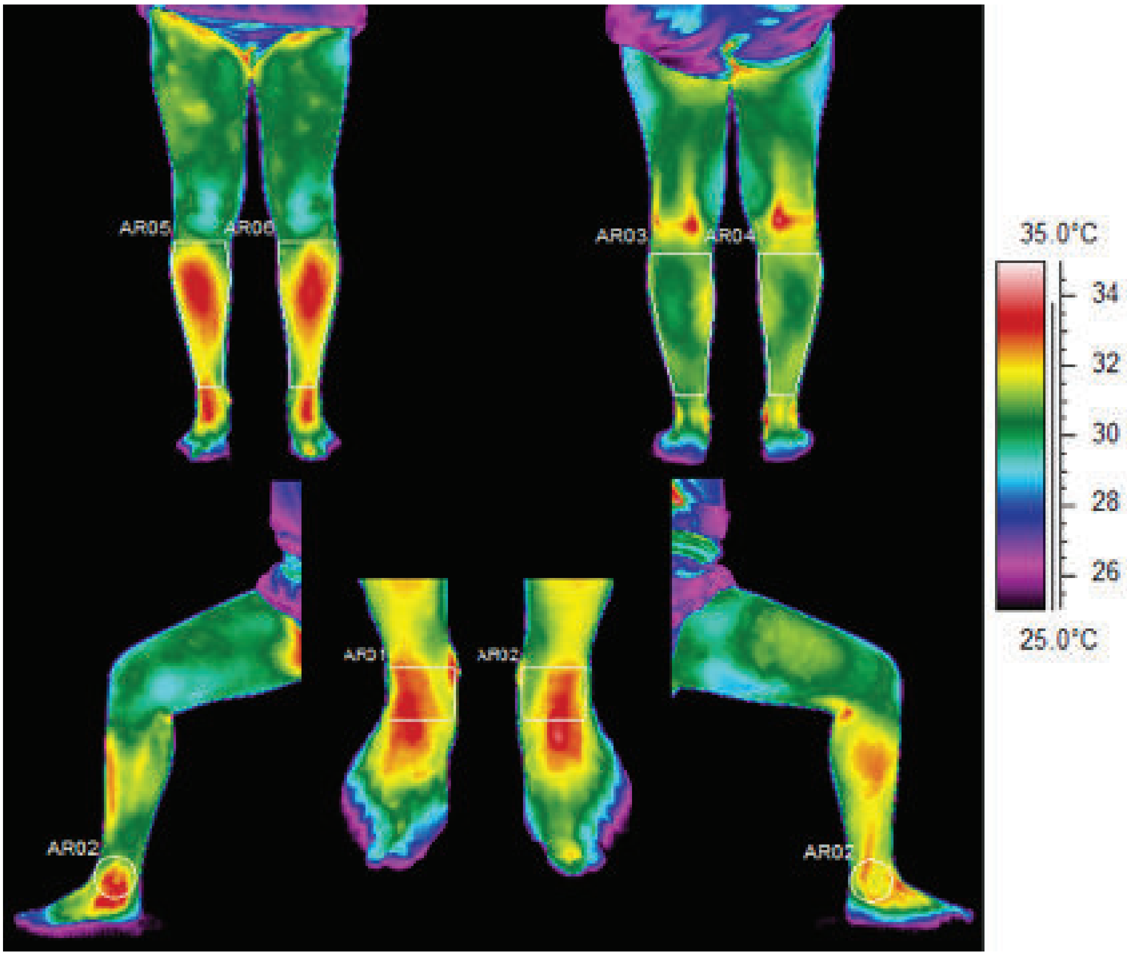

Figure 1. ROIs selected to be analyzed. Anterior aspect of the lower leg (up and left), posterior aspect of the lower leg (up and right), medial aspect of the ankle (down and left), lateral aspect of the ankle (down and right) and anterior aspect of the ankle (down and center)

using G*Power[26] to compute the statistical power of the analysis. In all statistical analysis, a two-sided p-value of less or equal to 0.05 identified significant differences.

Results

Although not the focus of this study, after the exposure to the experimental condition, TSk significantly decreased in all ROIs of both lower limbs in the control group ($p<0.05$). However, in the experimental group, although TSk decreased in all ROIs, significant differences were only observed in the anterior aspect of the right lower leg ($p=0.04$), in the medial aspect of the right ankle ($p=0.05$) and in the left lateral aspect of the ankle ($p=0.02$).

Thermal symmetry was higher (lower TSk difference) in the anterior aspect of the lower leg (0.16±0.13°C) and was lower (higher TSk differences) in the lateral aspect of the ankle (0.27±0.20°C). Thermal symmetry in the dorsal aspect of the lower leg was 0.20±0.16°C, 0.26±0.21°C in the medial aspect of the ankle and 0.23±0.23 in the anterior aspect of the ankle. The results of the experimental procedure on thermal symmetry of the selected ROIs are expressed in Tables 2 (control group) and 3 (experimental group).

The side to side differences increased significantly in the lateral aspect of the ankle ($p=0.01$) and decreased significantly ($p=0.02$) in the anterior aspect of the ankle, but only in the experimental group. In both cases the effect size was considered moderate.[27]

Figures 2 and 3 illustrate the Bland-Altman analysis of comparing thermal symmetry in the anterior and lateral aspects of the ankle, respectively, before and after the exposure to WBV.

In the agreement between the right and left anterior aspects of the ankle (Figure 2) before the exposure to WBV, 100% of the differences are contained within the limits of agreement (LOA) and the mean difference between the measurement (bias) was -0.12ºC

Table 2. Thermal Symmetry (mean ± standard deviation) before and after the experimental procedure in the control group

Regions of Interest	n	Initial ΔT (ºC)	Final ΔT (ºC)	p	95% CI	ES	1-β
Lower Leg Anterior	18	0.14±0.11	0.13±0.09	0.87	[-0.050, 0.050]	0.03	0.05
Lower Leg Dorsal	18	0.17±0.08	0.17±0.14	0.78	[-0.050, 0.100]	0.05	0.05
Ankle (lateral)	18	0.15±0.20	0.21±0.14	0.94	[-0.100, 0.150]	0.01	0.05
Ankle (medial)	18	0.31±0.20	0.33±0.26	0.71	[-0.100, 0.100]	0.06	0.06
Ankle (anterior)	18	0.24±0.19	0.23±0.18	0.20	[-0.050, 0.200]	0.22	0.15

Note: results for significance (p), 95% confidence intervals (95% CI), effect size (ES) and statistical power (1-β).

Table 3. Thermal Symmetry (mean ± standard deviation) before and after the experimental procedure in the experimental group

Regions of Interest	n	Initial ΔT (ºC)	Final ΔT (ºC)	p	95% CI	ES	1-β
Lower Leg Anterior	18	0.19±0.14	0.19±0.19	0.82	[-0.100, 0.050]	0.04	0.05
Lower Leg Dorsal	18	0.22±0.21	0.18±0.14	0.73	[-0.150, 0.100]	0.06	0.06
Ankle (lateral)	18	0.23±0.20	0.38±0.30	0.01*	[0.050, 0.300]	0.42	0.45
Ankle (medial)	18	0.28±0.23	0.28±0.24	0.84	[-0.100, 0.100]	0.03	0.05
Ankle (anterior)	18	0.31±0.23	0.19±0.20	0.02*	[-0.200, -0.050]	0.38	0.37

Note: results for significance (p), 95% confidence intervals (95% CI), effect size (ES) and statistical power (1-β); (*) p<0.05

(LOA: -0.85 to 0.61°C). After the exposure to WBV, 94.4% of the differences are contained within the LOA and the bias increased to -0.16°C (LOA: -0.60 to 0.29°C).

In the agreement between the right and left lateral aspects of the ankle (figure 3) before the exposure to WBV, 83.3% of the differences are contained within the limits of agreement (LOA) and the bias is 0.06°C (LOA: -0.54 to 0.65°C). After the exposure to WBV, 94.4% of the differences are contained within the LOA and the bias increased to -0.12°C (LOA: -1.06 to 0.83°C).

Discussion

The proposed methodology was able to assess the immediate effects of WBV on thermal symmetry and the results of this study suggest that exposure to an acute bout of WBV (35Hz) significantly affects thermal symmetry in the ankle, specifically in the anterior and lateral aspects.

Looking into the literature, the WBV effects on skin temperature are not consensual and some authors reported an increase in TSk,[16, 28] others reported a lack of significant effects in TSk[14, 29] and others reported a decrease in TSk after exposure to WBV.[17-19] These differences may be related to the heterogeneity of WBV protocols. However, the focus of this research was to assess the effects of WBV in thermal symmetry and this heterogeneity will not be discussed.

Thermal symmetry may be used to identify potential areas where a disease or condition may be developing, granted that this disease or condition

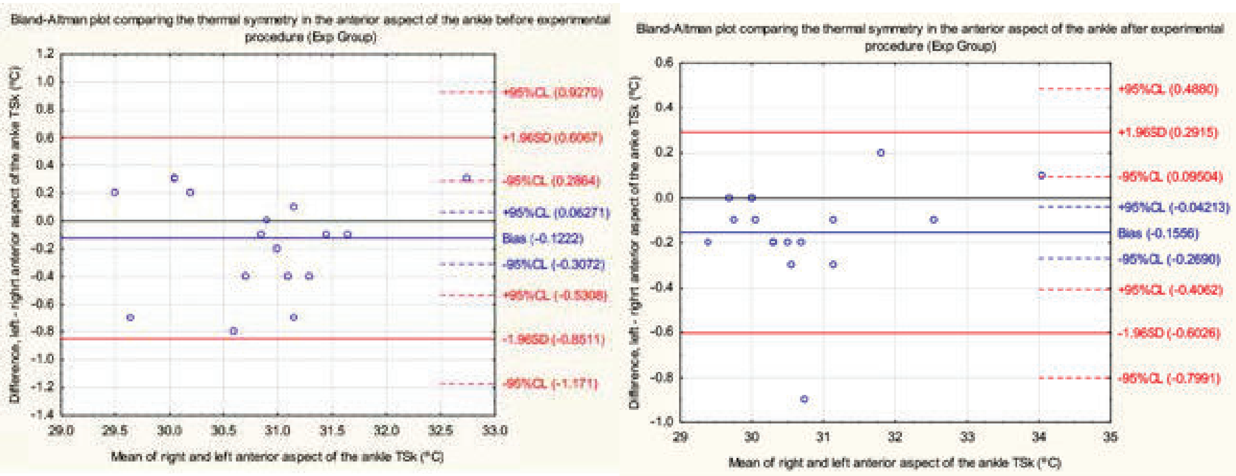

Figure 2. Bland-Altman plots representing the effect of WBV on thermal symmetry of the anterior aspect of the ankle in the experimental group

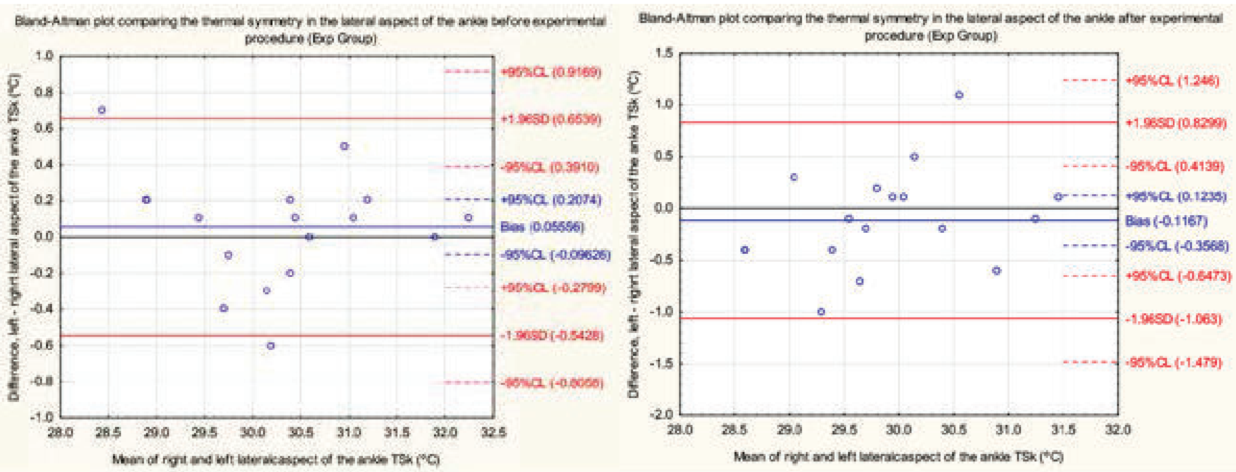

Figure 3. Bland-Altman plots representing the effect of WBV on thermal symmetry of the anterior aspect of the ankle in the experimental group

manifests unilaterally. Vardasca et al.[12] have proposed a thermal symmetry value of 0.5ºC as a threshold to identify potential problems. Thermal symmetry may also be used to identify asymmetries caused by the training program. The number of studies reporting the effects of WBV on thermal symmetry is very limited. Seixas et al.[17] has stated that the maximum side to side difference was observed in the lateral aspects of the lower limb. They also reported that WBV significantly increased the TSk differences between the right and left lower limbs, particularly in the posterior aspect of the thigh, anterior aspect of the knee and medial and lateral aspects of the ankle. Before the intervention, all thermal symmetry values were below 0.3ºC but after WBV, thermal symmetry values increased, especially in the anterior and medial aspects of the knee. In this study, thermal symmetry values before WBV were below 0.3ºC and after the experimental procedure, in the control group, thermal symmetry values have not changed significantly. However, in the experimental group, significant changes occurred in the lateral and anterior aspect of the ankle. These changes were not consistent, and side to side TSk differences increased in the lateral aspect of the ankle and decreased in the anterior aspect of the ankle. Despite this inconsistency the findings are clinically relevant, suggesting that the effects of WBV are not symmetrical and may affect both lower limbs in a different manner. The effects on thermal symmetry reported in this study are different to those of previous research reporting no effect of WBV, using the same vibration parameters, in thermal symmetry of the lower legs and ankle of both control and experimental groups.[17] However, differences in sample size and biological characteristics of the participants (e.g. gender, BMI) may have contributed to the results.

Previous research has suggested that the effects of vibration were more intense in the structures closer to the vibration platform.[30] In this study, significant changes in thermal symmetry were found in the ankle but not in the lower leg, which may be related to the proximity to the vibration platform. In the Bland-Altman analysis the y-axis represents the differences between the left and right sides and was calculated as TSk in the left side minus TSk in the right side. In the anterior aspect of the ankle, after WBV, the bias increased, becoming more negative, which means that TSk in the right side was higher relatively to the left side. In the lateral aspect of the ankle, before WBV the bias was positive (higher TSk in the left side) and became negative after WBV, suggesting that TSk was higher in the right side relatively to the left side. Although the effects of WBV on thermal symmetry seemed inconsistent at a first glance, in fact they were similar and the decrease in TSk in the left side was higher relatively to the right side in both ROIs. The Bland-Altman analysis proved very important to understand this trend and only looking into the absolute difference between both sides would not be enough to understand it.

TSk decreased in all ROIs in both groups. These results may be justified by the increased need of blood supply during vibration that may be responsible for shunting blood flow from the integumentary system to active muscles.[5, 18] Therefore, we can argue that, at the anterior and lateral aspect of the ankle, the effects of WBV were not symmetrical, relatively increasing TSk in the right side. In the control group significant differences in thermal symmetry were not observed, suggesting that the effects of WBV are not affected equally in both lower limbs and that limb dominance may play a role in the process.

This study has some limitations. Sample size is relatively small, which affected the statistical power of the analysis. Although the results suggest that the effects of WBV might be asymmetrical, we have not controlled for causes of such asymmetry, for instance the load in the lower limbs or changes in lower limb stiffness could have been different. Moreover, only one vibration frequency was tested and different vibration frequencies may induce different results.

Conclusion

Isometrically maintaining a position of 45º of knee flexion for five minutes is enough to decrease ankle TSk significantly, but not thermal symmetry.

Acute exposure to WBV (35 Hz, 5-6 mm amplitude for 5 minutes) significantly affected thermal symmetry in the anterior and lateral aspects of the ankle.

Although the results of this study should be interpreted with care, given the low statistical power, caution should be taken by health and exercise professionals before prescribing this exercise modality since future research is still needed to clarify the potential mechanisms influencing microcirculation.

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