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Cardiac autonomic response during recovery using whole-body vibration after maximal cardiopulmonary exercise test

Respuesta cardiaca autónoma durante la recuperación utilizando vibración de cuerpo completo, después de una prueba de ejercicio cardiopulmonar máxima

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Abstract. In the last years the nervous and cardiovascular response to exercise has taken on an important relevance, both in sport and health field. In this line, accelerating cardiovascular appears to play a key role in various sports fields. The study aims to examine and compare the acute effect of whole-body vibration (WBV) on cardiac autonomic response after maximal exercise in university runners and physical education student. Twenty men participated in a cross-over study, 10 university runners team (UR) and 10 physical education student (PES) with ages around 18 to 24 years. In each condition, was perform an incremental cardiopulmonary exercise test followed (i) active recovery time using WBV (25 Hz and peak displacement of four mm) and (ii) passive recovery period (no WBV; 0 Hz-0 mm), separated by seven days. Active recovery consisted in one minute seated using WBV and one minute no WBV by six times (12 minutes) more five minutes of passive recovery, and passive recovery consisted in 17 min seated on platform without vibration. Active recovery had significant differences compare to passive recovery ($P<0.05$). Furthermore, in active recovery, PES had better heart rate response than UR group, however results were not significative. There was not a clear relation between the lineal components of heart rate variability (HRV) in our results. WBV has positive effect in participant's recovery, however, is necessary establish protocols about the intensities and time adequate for allow accelerate recovery the parasympathetic reactivity, for that reason yet can't conclude clearly respect to the more effectivity intensity WBV depending to characteristic of subject.

Keywords: Vibrating Platform, Active and Passive Recovery, Heart Rate Variability, University runners, Physical education student.

Resumen. En los últimos años la respuesta nerviosa y cardiovascular al ejercicio ha adquirido una relevancia importante, tanto en el ámbito del deporte como de la salud. Por tanto, la aceleración de la recuperación cardiovascular parece desempeñar un papel clave en varios campos. El objetivo del estudio es analizar y comparar el efecto agudo de la vibración de cuerpo completo (VCC), en la respuesta cardíaca autónoma después del ejercicio máximo en corredores universitarios (CU) y estudiantes de educación física (EEF). Veinte hombres participaron en un estudio cruzado, 10 CU y 10 EEF con edades entre 18 y 24 años. En cada evaluación, se realizó una prueba cardiopulmonar incremental seguida de (i) tiempo de recuperación activa usando VCC (25 Hz y desplazamiento máx. de cuatro mm) y (ii) período de recuperación pasiva (sin VCC; 0 Hz -0 mm), separados por siete días. La recuperación activa consistió en un minuto sentado usando WBV y un minuto sin WBV seis veces (12 min), más cinco minutos de recuperación pasiva; la recuperación pasiva y esta consistió en 17 minutos sentado en plataforma sin vibración. La recuperación activa tuvo diferencias significativas en comparación con recuperación pasiva ($p<0.05$). Además, en recuperación activa, EEF tuvo una mejor respuesta de frecuencia cardíaca que el grupo CU, sin embargo, los resultados no fueron significativos. Por último, no se logró establecer una relación clara entre los componentes lineales de la variabilidad del ritmo cardiaco (VRC) en nuestros resultados. La VCC tiene un efecto positivo en la recuperación de los sujetos, sin embargo, es necesario establecer protocolos sobre las intensidades y tiempo adecuado para permitir acelerar la recuperación de la reactividad parasimpática, por esa razón aún no se puede concluir claramente respecto al mejor protocolo VVC dependiendo de la característica del sujeto.

Palabras claves: Plataforma Vibratoria, Recuperación Activa y Pasiva, Variabilidad de la Frecuencia Cardíaca, Corredores Universitarios, Estudiantes de Educación Física.

Introducción

In the last years the nervous and cardiovascular response to exercise has taken on an important relevance, both in sport and health field (Dantas et al., 2018). Therefore, accelerating physical recovery appears to play a key role in various fields. In this regard, the literature has shown that WBV training exerts acute and chronic improvements in vascular function due to the mechanical effect of the vibrations on the muscles (Galaz-Campos et al., 2020), especially improving venous blood return, and increases sympathovagal balance (Figueroa et al., 2012; Sañudo et al., 2016), partially improving the recovery of the subjects. The autonomic nervous system plays a central role in cardiovascular homeostasis both during and after exercise (Aubert, Seps & Beckers, 2003), for which several methods have been used (eg, whole body vibration [WBV], immersion in water, etc.) to activate the mechanisms that contribute to increasing parasympathetic activity (Galaz-Campos et al., 2020), which causes a decrease in heart rate and promotes

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cardiovascular recovery after exercise (O'Leary, 1993)

Non-invasive and easy methods to determine these responses have been both heart rate (HR) and heart rate variability (HRV), the latter being an uncomplicated way to determine the behavior of cardiac autonomic activity (Bellenger et al., 2016). The HR is the mostly used physiological indicator at rest, during and after exercise; a slower HR recovery after exercise is a good fitness parameter that provide important information, about different mechanisms of physiological control of the body that reacts to physical activity (Sydó et al., 2018). On other hand, the HRV detects the sympathetic-vagal relationship, which is evaluated through the R-R intervals that indicate the differences time between two consecutives beats, more specifically the time that passes from one ventricular contraction to the next, that difference is regulated by the nervous system and has demonstrated different behaviors between trained and sedentary subjects (Gojanovic et al., 2014). It has been seen that as a result of adaptations to physical exercise in trained subjects, HRV at rest is increased, indicating an activity with predominance of the parasympathetic nervous system (ChuDuc et al., 2013; Danieli et al., 2014).

For the determination of the sympathetic-vagal balance, high-frequency (HF) values associated with a parasympathetic predominance have been used (Pagani et al., 1986), and low-frequency (LF) values that are related to a sympathetic and parasympathetic predominance as a whole, being an important indicator the LF/ HF ratio, an index that, when increased, would reflect a more sympathetic modulation and, when decreasing, would reflect a more parasympathetic modulation (Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology, 2009). Regarding whole body vibration (WBV), it has recently been studied as an alternative and complementary exercise method, in sedentary and even in athletes, it has shown positive effects on muscle strength, flexibility and even energy (Kosar et al., 2012), as well as its application in the areas of health, rehabilitation and sports performance (Rittweger, 2010).

In addition, WBV has the ability to stimulate a large number of muscle fibers and produce contractions, which generates an increase in blood flow, in turn promoting peripheral blood circulation, vasodilation processes and widening of capillaries (García et al., 2006). This could influence the acceleration of nutrient transport and metabolic waste evacuation (Kerschan-Schindl et al., 2001), improving the subject's recovery process. In turn, Gojanovic et al. (2014), points out that the response to metabolic rate and HR influenced by vibratory training, varies more by the level of physical condition and the type of training. Thus, trained subjects would have greater effects than untrained subjects (Luo et al., 2005).

However, few studies have determined the effect that the vibrating platform would have on HR and HRV. For their part, Sañudo et al. (Sañudo et al., 2013) showed that WBV would stimulate cardiovascular recovery through HR, finding that subjects decreased their HR faster when recovery was with vibration compared to one without vibration, despite this, their results did not They were conclusive on the effects of autonomic modulation in subjects.

For this reason, due to the lack of clarity regarding the relationship between WBV and cardiovascular recovery, this study aims to analyze and compare the acute effect of WBV on cardiac autonomic response after maximal exercise in university runners and physical education student, to verify if there are associated differences active recovery with WBV, and if it is influenced by the level of physical condition.

Material and methods

Experimental Design

A crossover-counterbalanced design was carried out in separated by seven days; participants realized the protocol the same day of each week at same hour and under similar conditions of temperature (20-25 Cº) to remove biases regarding the influence of temperature on performance and HR parameters. Both groups were subjected to the following protocol: Initially, a rest period followed by a maximal cardiopulmonary exercise testing (CPET) and subsequently, a recovery period, where each individual was randomly assigned for his recovery period, either, first day using WBV and the next session, without WBV (no WBV), or vice versa, where no WBV was applicate in first day and second session was used WBV (Figure I).

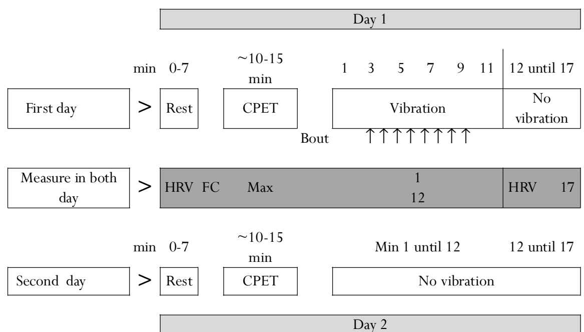

Figure I. Design of intervention

Participants

Twenty men volunteers were enrolled for the study: 10 university runners team (UR) and 10 physical education students (PES). Exclusion criteria were present pathologies or any affection at the time of the study, present bony or muscular lesions, any alcohol and diuretics consumption during the participation in the study. For the UR group, they had to meet 3 requirements: Train 5 days by week, belong to an athletic club and compete once a month. This present study was conducted out according with the international deontological standard for research involving human subjects set forth in the declaration of Helsinki. All participants signed informed consent and were made aware of procedures and objectives.

Measurement protocol Rest

When arriving at the laboratory was measured to each subject: height using a stadiometer (model 216, Seca®, Germany); body weight with a scale previously calibrated to an accuracy of 0.1 kg (model TBF-300A, Tanita®, Japan), and total body water through bioelectrical Impedance analysis (INBODY S10®, Japan). Subsequently, they were given the following resting position: Sitting for 7 minutes with their feet on the platform, keeping their thighs almost together and the knees and hips flexed 90°, the final 5 minutes were considered to calculate the resting HRV values. This protocol was carried out similarly on day with vibrations (WBV) and day without vibrations (no WBV).

Cardiopulmonary exercise testing (CPET)

After the initial rest period in which the HRV was recorded at rest, the subjects performed a warm-up (5 min, 8 km/h) on a treadmill (Technogym ™ «Run excite 700») and subsequently performed CPET. Each subject performed one incremental exercise to exhaustion to determine his maximum power at VO_{2max} (pVO_{2max}). Gas analyses were performed using a stationary spiroergometric device measuring in the breath-by-breath mode (Metalyzer 3B, Cortex). The maximal effort was stablished when the subject met the following criteria: (i) a plateau of VO_2 defined as no change (<150 mL $min^{»1}$) in VO2 from the previous stage; (ii) an respiratory exchange ratio (RER) > 1.1; and (iii) HR > 95% of age-predictum maximum.

Recovery period

After the incremental exercise test, all participants were seated with their feet on a vibratory platform (Fitvibe, GymnaUniphy NV, Bilzen, Belgium) keeping their thighs abducted and the knees and hips flexed 90æ%, the same position that during initial rest period and similar to a previous study (Sañudo et al., 2013). Was established randomly the 17 minutes recovery period for each person: First day, with vibration (WBV, 25 Hz frequency, 4 mm amplitude) or without vibration (noWBV, 0 Hz, 0 mm) and the second testing day was opposite procedure received the first day.

The protocol of recovery period with WBV consisted in six 1 min sets separated by 1 min inter-set rest periods in the seated position. Recovery period with WBV was applied for 12 min, after finished the protocol of vibrations, the subjects remained seated by 5 minutes more with the objective to record the HVR. This position was used for avoid possible changes of the HRV associated to the position of the body. The protocol of noWBV was 17 minutes seated in the same position, and in the 12 minutes, started the record of HRV during last 5 minutes (Figure 1).

Measure heart rate and heart rate variability

The HR was recorded during recovery period in the minute 1, minute 12 and minute 17, in both days. HR and heart rate variability HRV were measured with Polar V800 in seated position. Each day were taken two registers of HRV, the first was during the rest, and the second was after to CPET, during the last 5 minutes of the recovery, both using recovery WBV and no WBV in another session.

Frequency-Domain and Time-Domain indexes

Frequency-Domains indexes

Both days we considered frequency-domain measures of HRV like an index of autonomic balance. The power spectral was determinate using fast-Fourier transform. Components of frequency-domain were expressed in normalized united which considered low frequency (LF) between 0.04-0.15 Hz and high frequency (HF) within 0.15 – 0.4 Hz. The sympathovagal balance was determined through LF/HF ratio.

Time-domain index

The variation in heart rate was evaluated in intervals and the standard deviation of the normal R-R intervals (SDNN) was used to estimate the cycles, this is the most common method. Using the square root of the variance. Since the variance is mathematically equal to the total power of the spectral analysis, SDNN reflects all the cyclical components responsible for the variability in the recording period (American Heart Association, 1996). A decreased SDNN is clinically relevant since it is independently associated with cardiomyopathy (Cardoso, Moraes, Leite, & Salles, 2014).

Statistical Analyses

Values are expressed as mean and standard deviation (SD). The differences between the UR and PES groups, as well as in the rest and recovery period and the effects using WBV and no WBV were obtained by means of the 2-way analysis of variance (ANOVA) with repeated measures. Normality of the data was analyzed with the Shapiro-Wilk test. Post-hoc analysis with Bonferroni method was performed. Variables which were not normally distributed, were transformed using the natural logarithm (ln) before statistical analysis. All statistical analyses were obtained using SPSS (version 21 for Macintosh). In all cases, statistical significance was considered for $p<0.05$.

Results

Participants characteristics

Table I shows the participants characteristics of both groups. We observed significative differences ($p<0.05$) on weight, BMI and VO_{2max}, UR group had lower value in weight and higher values on VO_{2max} that PES group.

Heart rate

Table II shows HR obtained using WBV and no WBV both at rest and during recovery time after a maximal test. HR was significantly higher than rest time in both groups ($p<0.05$) throughout the recovery, regardless of the use or not of the WBV. There were no significant differences comparing WBV and no WBV values in the same group. There just were significant differences during minute 17 of recovery when comparing separately each intervention (WBV and no WBV) between PES v/s UR group ($p<0.05$) being lower the UR values.

Table III shows HR recovery time by each group with intervention of WBV and no WBV with respect to the maximum HR reached during the maximal exercise test. There were no significant differences comparing WBV and no WBV values for each group. Significant difference shows in the minute 17 of HR recovery when compare no WBV intervention between UR v/s PES group ($p<0.05$).

Figure II shows Ä HR corresponding to recovery of heart rate respect to maximum reaching this day. In figure IIA, it is shown that there is no significant difference between the two interventions, but rather a borderline effect ($p=0.069$). In figure IIC, corresponding to effect of the intervention in PES group, shows a significative difference between WBV v/s no WBV interventions in the 17 minutes of recovery time.

Table I. Participants characteristics

Outcome	Physical Education Student (PES) N= 10	University Runners (UR) N= 10
Age (year)	22.0 ± 2.9	21.3 ± 2.2
Weight (kg)	80.1 ± 8.9	65.6 ± 7.2 *
Height (cm)	176.3 ± 2.8	174.0 ± 0.1
BMI (kg/m²)	25.8 ± 3.3	21.6 ± 0.6 *
VO_2max (ml/kg/min)	48.7 ± 6.7	65.7 ± 3.2 *

* Significantly different of PES ($p<0.05$). BMI, body mass index. VO_{2max}, maximal oxygen uptake. Values are means ± SD.

Table II. Heart rate at rest and after a maximal exercise test with whole-body vibration (WBV) and without vibration (no WBV) trials.

Group Time	PES		UR	
	WBV	noWBV	WBV	noWBV
Rest	71.3 ± 7.3	68.9 ± 12.3	65.6 ± 9.6	68.4 ± 10.8
Max HR reached	194.0 ± 6.2	191.3 ± 6.0	192.7 ± 6.6	192.4 ± 6.8
Min 1 Recovery	126.7 ± 7.1	129.4 ± 7.5	126.4 ± 20.6	127.6 ± 15.9
Min 12 Recovery	107.7 ± 5.2	110.9 ± 8.5	102.0 ± 7.0	106.1 ± 7.7
Min 17 Recovery	103.0 ± 4.4	105.9 ± 5.7	96.1 ± 7.4*	96.9 ± 6.1†

Values are means ± SD. *Significantly different of PES group in the same period of time during WBV; †Significantly different of PES group in the same period of time during no WBV ($p<0.05$).

Table III. Heart rate recovery time by each group with whole-body vibration (WBV) and without vibration (no WBV) intervention respect to the maximum heart rate reached during the maximal exercise test.

Group	PES		UR	
Time	WBV	noWBV	WBV	noWBV
Max HR reached	194.0 ± 6.2	191.3 ± 6.0	192.7 ± 6.6	192.4 ± 6.8
? Recovery min 1	67.3 ± 6.4	61.9 ± 8.0	66.3 ± 20.2	64.9 ± 16.4
? Recovery min 12	86.3 ± 4.5	80.4 ± 9.1	90.7 ± 7.7	86.3 ± 7.7
? Recovery min 17	91.0 ± 4.2	86.3 ± 7.7 *	96.6 ± 8.8	95.6 ± 7.0

Values are means ± SD. PES: physical education student. UR: university runners. *Significant difference between PES v/s UR using no WBV intervention in the same recovery time.

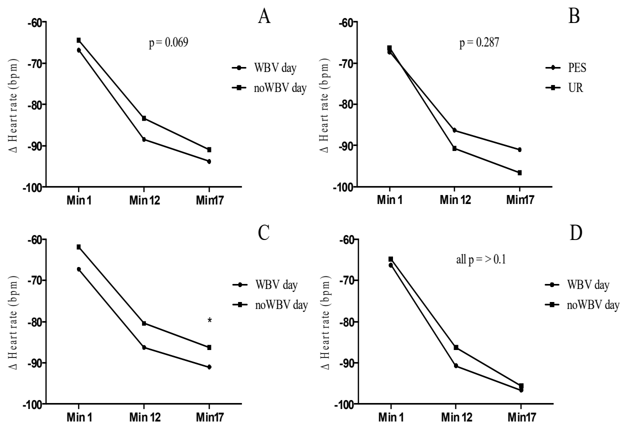

Figure II. Δ Heart rate corresponding to recovery of heart rate respect to maximum reaching this day; A: Corresponding to global effect of intervention; B: corresponding to global effect of group; C: corresponding to effect of intervention in Physical education student group; D: corresponding to effect of intervention in University runners group; * $p= 0.032$.

HRV

Figure III shows the HRV values in the UR and PES group obtained using WBV and not WBV, both at rest and during recovery time after a maximum test. The results were the following.

SDNN, significant differences were obtained when comparing:

a) Rest v / s recovery time, independent of the intervention used (WBV or not WBV) in both groups.
b) Significant differences were also found when

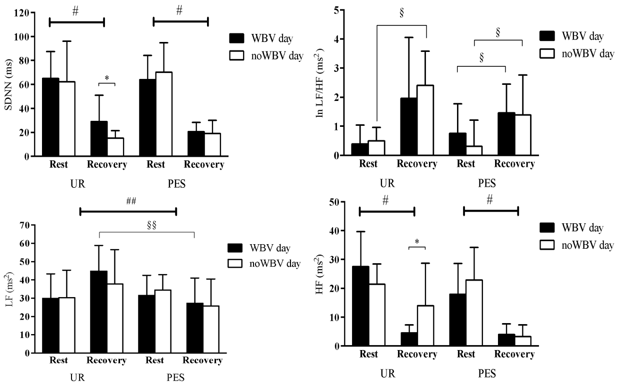

Figure III. Mean values of each heart rate variability indicator. SDNN: standard deviation of normal beats. LF: Low frequency band. HF: High frequency band. ln LF/HF: Natural log transformation of LF/HF ratio. UR: University Runners. PES: Physical education student. # Indicate global effect of time (all $p<0.005$). ## Indicate effect of interaction time*group ($p<0.005$). *Indicate significant difference between interventions ($p<0.05$) in the same group. §Indicate significant difference between rest and recovery in the same intervention. §§Indicate significant difference between group in the same time and intervention.

comparing the intervention of WBV v / s non-WBV in recovery time, of UR group.

LF Significant differences when comparing:

a) UR group v / s PES using WBV intervention at recovery time.

LF / HF Significant differences when comparing:

a) Rest v / s recovery time using WBV in PES group. b) Rest v / s recovery time using no WBV in UR group.

HF Significant differences when comparing:

a) Rest v/s recovery time using WBV and not WBV in PES group. b) Rest v / s recovery time using WBV in UR group c) Use of WBV v/s not WBV during the Recovery time in UR group.

Furthermore, the **SDNN, LF / HF** and **HF** variables show significant differences that indicate an overall effect between rest and recovery time for both groups. On the other hand, the LF variable shows an overall effect between time and groups.

Discussion

The aim of this study was to analyze the acute effect of WBV over HR recovery and HRV after a maximal exercise and if it is influenced by the physical condition level. The findings indicate that using a WBV (25 Hz, 4 mm) protocol of 12 minutes (six set of 1 minute, separated by rest periods of 1 minute, in a sitting position), positively influences more in HR recovery that in HRV, showing the biggest decline at 17 minutes after exercise finished, especially in a group of untrained people.

To our knowledge, is the first time that compared the response of HR recovery and HRV using a protocol of WBV after a maximal exercise in university runners and physical education student. To date, studies about the acute HR and HRV recovery using WBV after exercise are limited (Dipla et al., 2016; Jiao, Li et al., 2004; Sañudo et al., 2016, 2013).

Considering that regular trained induce chronic changes that influence of the vagus nerves on cardiac excitability (Besnier et al., 2017; Danson & Paterson, 2003), that increase the baroreflex sensitivity (Duarte et al., 2015; Kamijo et al., 2011; Lehrer et al., 2003). HR recovery after exercise is influenced by parasympathetic reactivation and sympathetic recovery at resting levels and is an important indicator of sympathetic/parasympathetic balance (Buchheit et al., 2007; Coote, 2010; Duarte et al., 2015; Kingsley & Figueroa, 2016). In turn also using different components of heart rate variability (time and frequency domain) has been confirmed the parasympathetic reactivation after exercise with a significant reduction in the HF power by several studies (Brown & Brown, 2007; Goldberger, 2006; Hautala et al., 2001; Kaikkonen et al., 2007; Martinmäki & Rusko, 2007). In addition, it is currently is a method used by trainers of evaluating acute and chronical effects of different types of training and prevent overtraining (Buchheit et al., 2010; Plews, 2013; Plews et al., 2013; Seiler et al., 2007).

Comparisons between untrained subjects and highly trained endurance athletes have showed that heart rate falls more quickly after a bout of high-intensity exercise in the trained persons (Bellenger et al., 2016; Borresen & Lambert, 2008; Brown & Brown, 2007; Danieli et al., 2014), and as expected, in our results, the response of HR recovery was increasing directly proportional to the passing of the minutes after the end of the exercise in both groups and was lowest in UR group that PES group specially in 17 minutes (Table 2 and Figure II-B).

WBV have been used as an active recovery because produce reflex neuromuscular stimulation, (Herrero et al., 2011) causing a lower heart rate during recovery time that could be associated by an increased venous return as result of an active muscle pump (Takahashi et al., 2005).

In our study, there was no significant effects when compared WBV v/s NoWBV interventions in both groups, but there showed a global limit effect (0.69) and could explain that HR recovery in PES group was similar to HR recovery of UR group without WBV, however, needs more statistical power to determine effects that WBV intervention could have generated during the recovery time (Figure 2-A and Table II). Our investigation used a similar WBV protocol with that Sañudo et al. (Sañudo et al., 2013) assessed the WBV effects in young healthy males (seated with their feet on a vibratory platform during 12 min of recovery after an exercise test to exhaustion), it reported reductions in HR during the recovery period after WBV compared to a recovery without WBV, it being our results similar to obtained by this previous study. Sañudo et al. mention that WBV with his reflex muscles contractions improves venous return and this would offset an increased HR post-exercise observed without WBV (Sañudo et al., 2016).

Ours results about HRV components, in general there were not significative differences between both groups and interventions, but they followed the same trends that previous studies that used WBV during recovery time after exercise how was the decrease in HF and LF/HF power and increase in LF power. Sañudo et al. (Sañudo et al., 2013) found similar reductions in HF and increases in LF and LF/HF, however, his results were not conclusive to the HRV lineal analyses, at the same that our results. Jiao et al. (Jiao et al., 2004) points out a significant decrease in HF power and increase in LF power after a 90-minute sitting session on a vibration device with 2 types of vertical sinusoidal vibrations in healthy young men (1-8 Hz, 7-7 mm of amplitude and 6 Hz, 0-7 mm of amplitude).

LF/HF was significantly higher in the group that used the highest frequency, which suggests a correlation in which to more intense WBV frequency will produce a bigger sympathetic activity. This could be explained that an increase in muscle activation occurs with higher WBV frequencies, for that reason it is important mentions that the response to effects of WBV is mediated by different factors, like the intensity and amplitude of vibration. (Kim & Seo, 2013). Apparently in low intensities the effect could be mitigated by the exercise capacity of the subject (Jiao et al., 2004). Therefore, considering the few studies to date, it is necessary to determine the most effective intensity and amplitude to achieve a better recovery (Wong & Figueroa, 2018).

The current study has limitations due to having a small sample that can influence the statistical power, however, the counterbalanced and crossover design could minimize this limitation. Another limitation is not having made a more extensive measurement during the post-exercise period to determine the influence of the WBV on the initial resting values are recovered. Future studies should examine the effect of a longer episode of WBV on autonomic cardiovascular modulation and hemodynamics. It is also necessary to investigate about most useful parameters of WBV (intensity, amplitude and frequency) to favor a better recovery after an exercise.

In conclusion, using a protocol WBV of 12 minutes after maximal exercise, a PES group had better heart rate recovery response that UR group, however, results were not significative. WBV has positive effect in subject's recovery, however is necessary establish protocols about the intensities and time adequate for allow accelerate recovery the parasympathetic reactivity.

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