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Heart rate variability and blood pressure during and after three CrossFit® sessions
Variabilidad de la frecuencia cardíaca y de la presión arterial durante y después de tres sesiones de CrossFit®

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Abstract. CrossFit® is a training program characterized by high intensity stimulus with constantly varied and multifunctional movements that induces a significant range of physiological, hemodynamic and biochemical responses. Heart rate variability (HRV) can be used to measure how individuals react to physiological stress and fatigue. Thus, the aim of this study was to verify HRV and blood pressure acute responses during and after three sessions of Crossfit®. Nine subjects with more than one year of experience performed three different sessions of CrossFit® to verify the response of systolic blood pressure (SBP), diastolic blood pressure (DBP) and HRV. Significant reductions in HRV were observed through parasympathetic indexes (High Frequency(HF), $p<0.001$) and an increase in the activity of sympathetic indexes (Low Frequency (LF), $p < 0.01$; LF/HF, $p<0.001$) after all Crossfit® workouts. SBP decreased ($p<0.05$) and there were no significant differences between workouts of the day in both HRV and SBP. Different CrossFit® sessions induced similar activity of the autonomic nervous system with reduced HRV and post-exercise hypotension.
Keywords. high intensity interval training; Fran; Megan; Diane; autonomic response; post-exercise hypotensive effect.

Resumen. CrossFit® es un programa de entrenamiento caracterizado por estímulos de alta intensidad basado en ejercicios funcionales que varían constantemente y que inducen a importantes demandas fisiológicas, hemodinámicas y bioquímicas. La variabilidad de la frecuencia cardíaca (VFC) es usado como un indicador un indicador de estrés fisiológico y fatiga. El objetivo de este estudio fue analizar las respuestas agudas de la VFC y la presión arterial durante y después de tres sesiones diferentes de Crossfit®. Nueve sujetos con más de un año de experiencia realizaron tres sesiones diferentes de CrossFit® en las que se analizó la respuesta de la presión arterial sistólica (PAS), presión arterial diastólica (PAD) y VFC. Se observaron reducciones significativas en la VFC a través de los índices parasimpáticos (Alta Frecuencia (HF), $p<0.001$) y un aumento en la actividad de los índices simpáticos (Baja Frecuencia (LF), $p<0.01$; LF/HF, $p<0.001$) tras la realización de las tres sesiones. La PAS disminuyó ($p<0.05$) y no hubo diferencias significativas entre los entrenamientos del día tanto en la VFC como en la PAS. Las tres sesiones de CrossFit® analizadas indujeron una actividad similar, reduciendo la actividad del sistema nervioso autónomo medida mediante HRV, así como una hipotensión post-ejercicio.
Palabras clave. entrenamiento interválico de alta intensidad; Fran; Megan; Diane; respuesta autonómica; hipotensión post-ejercicio.

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Introduction

CrossFit® is a training modality, very popular and with a high motivational factor (Bellar *et al.,* 2015; Oliver-López *et al.,* 2022). Its physical training program is characterized by high intensity stimulus with varied and multifunctional movements (Leitão *et al.,* 2021; Sánchez-Silva *et al.,* 2021) performed through exercises such as metabolic conditioning, gymnastic using body weight and Olympic lifting movements (Glassman *et al.,* 2007; Tibana *et al.,* 2015; Kramer *et al.,* 2016; Montalvo *et al.,* 2017). During their execution successive repetitions are requested and very restricted rest is used (Tibana *et al.,* 2016; Weisenthal *et al.,* 2014) or even without any recovery intervals (Butcher *et al.,* 2015).

The high-intensity of CrossFit® generates significant changes in physiological, metabolic, inflammatory, hormonal, hemodynamic and autonomic responses (Jacob *et al.,* 2020; Nájera *et al.,* 2022; Costa *et al.,* 2021). Thus, the acute effect of this training method is able to increase blood lactate concentration (Maté-Muñoz *et al.,* 2017), oxygen consumption (Bellar *et al.,* 2015), heart rate (Claudino *et al.,* 2018) and rate of perceived exertion (Tibana *et al.,* 2018). Furthermore, it has a hypotensive effect (Tibana *et al.,* 2017) and reduce heart rate variability (HRV) (Williams *et al.,* 2017).

Heart rate variability (HRV) is considered a time-efficient non-invasive physiological marker of autonomic nervous system modulation (Task Force, 1996; Le Meur *et al.* 2017; Hernández-Cruz *et al.,* 2022) and is easy to perform and low cost. In the context of sport, HRV allows the evaluation of the adaptations of training loads, which facilitates the control of training, detects possible causes of fatigue early and assists in the necessary modifications in the training plan (Olivares-Arancibia *et al.,* 2021; Nieto-Jimenez *et al.,* 2020). Corrales *et al.* (2021) showed that the indices of the RMSSD curve can be used as indicators of internal load and, therefore, imply different responses among individuals when subjected to the same external loads. Therefore, HRV is adequate to control training load. Williams *et al.* (2017) studied the relationship between reduced HRV and increased injury after 16 weeks of CrossFit® training and found that athletes who showed a RMSSD and parasympathetic control reduction were more likely to have some type of musculoskeletal overuse injury. Shaun and Vecchio (2018) when comparing autonomic responses between two different protocols, observed that HIIT based on full-body exercises (burpee; mountain climber; jumping jacks; squat, thruster) resulted in high parasympathetic inhibition immediately after the training session, with subsequent recovery within 24 hours. Kliszczewicz *et al.* (2018) showed that short duration (for time) and long duration (AMRAP) high intensity functional training (HIFT) protocols demonstrated significant depression of parasympathetic markers (RMSSD; HF) with concomitant increase in plasma catecholamines. The authors suggest that exercise intensity is the most influential factor in disrupting the autonomic nervous system, creating equivalent cardiovascular stress. However, Cardoso *et al.* (2021) verified that 12 weeks of Crossift® showed no significant difference in HRV geometric indices, among which, the instantaneous beat-to-beat interval variability (SD1), the long-term variability of continuous RR intervals (SD2) and the SD1/SD2 ratio, which could be justified by the level of conditioning of the research volunteers.

To identify the hemodynamic responses of CrossFit® Tibana *et al.* (2017) submitted a group to two different CrossFit® workouts that involved weightlifting exercises and gymnastic movements, one session included Olympic lifting while the other was more metabolic with the execution of calisthenic exercises. Both protocols were able to present post-exercise hypotensive effect (PEH) without differences between the protocols.

The literature has focused on the HRV response in different sports (Corrales *et al.,* 2021; Nieto-Jimenez et al;. 2020), strength training programs (Oliveira *et al.,* 2019), aerobic training protocols (Schaun & Vecchio, 2018) and high intensity functional interval training (HIFT) such as Crossfit® (Kliszczewicz *et al.,* 2018). However, in this, sessions may include WOD that serve as evaluative parameters, called benchmarks, which are not physiological controls of the training, but markers of comparison to the exerciser.

Despite the above, the literature did not show how the simultaneous behaviour of the autonomic and hemodynamic response could vary among different CrossFit® workouts of the day (WOD). Thus, the aim of this study was to verify the acute response of HRV and blood pressure during and after three sessions of CrossFit® workouts.

Methods

Experimental Design

An experimental approach, in randomized order, was used to identify the effect of different CrossFit workouts (Fran, Megan and Diane) on the responses of systolic blood pressure (SBP), diastolic blood pressure (DBP) and HRV. The volunteers came to the laboratory for four non-consecutive days, separated by 48 hours between them. During the first visit, anthropometric measurements and resting HR were measured, as well as familiarization with the devices used during data collection. After the first visit, the volunteers were randomly assigned to perform the three WOD and were asked not to perform the Valsalva manoeuvre during all exercise sessions.

Sample

Ten (n=10) normotensive male volunteers (29.6 ± 3.5 years; 81.6 ± 8.8 kg; 1.78 ± 0.0 m; 25.5 ± 1.8 kg / m2; 8.6 ± 3.6% G; 71.0 ± 10.0 HR rest; 184.7 ± 2.3 HR Máx), with minimum experience of one year in CrossFit® were recruited. Exclusion criteria were the presence of any type of bone, joint or muscle injury that could impair the execution of the movements, or the absence of ability to perform the proposed exercises. All procedures were approved by the local ethics committee (Doc46-CE-UTAD-2020), and were according to Helsinki declaration. All participants signed a consent form for their participation in the study.

Procedures

Workout of the Day (WOD)

The format of the WODs followed the order 21-15-9 sequential repetitions, and the exercises were: WOD Fran = Thruster (43 kg) and Pull up; WOD Diane = Deadlift (102 kg) and handstand push up; WOD Megan = Burpee, Kettlebell Swing (24 kg) and double under. All WOD's were performed at maximum intensity by all participants. Before all WOD's the participants performed a warm-up of 5 min of joint mobility and dynamic stretching exercises and two sets of 10 repetitions with body-weight and barbell weight in the WOD exercises, both separated by 5 min of rest.

Measures

Anthropometric data

Body mass and height obtained using a precision scale (Welmy®, model R / I W-200, Santa Bárbara d'Oste, Brazil) with a stadiometer. The 3-Site skinfold protocol was used for body fat assessment (Pollock and Jackson, 1993) with a caliper (Traditional, Cescorf, Porto Alegre, Brazil), with a sensitivity of 0.1 mm, 83 mm reading range and spring pressure of approximately 10 g / mm^2. The resolutions for anthropometric measurements were 0.1 kg for mass, 0.1 cm for height and 0.1 mm for skin folds.

HRV

HRV data were collected using a frequency meter (RS800Cx, Polar, Finland) and analysed with Kubios HRV Standard for Windows (64-bit Win7 SP 1 or 10). The selection of the stretches of analysis of the resting conditions and immediately after the last exercise was carried out through visual inspection of the distribution of the iR-R (ms), where the period with the greatest signal stability

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and a sampling frequency of 1,000 was selected, as recommended by the Task Force of the European Society of Cardiology, the North American Society of Pacing Electrophysiology (1996). The stretches that were analysed were: at rest (Pre); during exercise (During); immediately after the last exercise (Imed After); 15 minutes after the last exercise (Post 1); 30 minutes after the last exercise (Post 2); 45 minutes after the last exercise (Post 3); and 60 minutes after the last exercise (Post 4).The time domain analysis was performed from the mean HR (bpm), mean IRR (ms) and RMSSD indexes (ms), corresponding to the square root of the mean of the successive squared differences between the adjacent iR-R divided by the number of iR-R minus one, and SDNN (ms) - standard deviation of all iR-R. Analysis of the spectral power was carried out by the application of the fast Fourier transformation algorithm and the Welch periodogram, considering the components of very low (VLF: 0.0033 - 0.04 Hz), low (LF: 0.04 - 0.15 Hz) and high (HF: 0.15 - 0.40 Hz) frequency. Based on the results found, sympathovagal balances were calculated using the LF / HF ratio. The component values were expressed in standard units (n.u.).

Blood Pressure

SBP and DBP were measured using an automatic device with an oscillometric technique (Burdick 90217 Ultralite, USA). Before each use, the device was self-calibrated and used on the left arm with the participant in a sitting position, following the recommendations of the American College of Sports and Medicine (2017). During each experimental session, BP was assessed 10 minutes before each session after 10 minutes in rest, and at each fraction of 15 minutes after the exercise session until completing 60 minutes in the laboratory environment (Post 1, Post 2 and Post 3). All measurements were performed in the sitting position. A heart rate monitor (Polar Rs800CX, Finland) was used to verify heart rate (HR) both at rest and during exercise in both groups.

Statistical Analysis

Shapiro-Wilk and Levene's tests were used for analyses of variance normality and homogeneity, and data is reported as means ± standard deviation. If the assumptions of normality and homogeneity of variance were fulfilled, a one-way ANOVA with repeated measures and a Bonferroni's Post Hoc were used to compare HRV variables among the three WODs. For effect size we used Cohen's test using the following criteria: <0.35 trivial; 0.35-0.80 small; 0.80-1.50 moderate; and >1.5 large, according to the classification of recreationally trained individuals proposed by Rhea (2004).

Results

The descriptive data of HRV variables (Table 1) in the time domain demonstrated high variability, except pNN50 in Post 4. The frequency domain showed high variability at all times and WODs. The exception was HF at the moment Pre of Fran WOD. The SBP showed high variability only in the last three measurements post- Fran, while the DBP was uniform in all measured conditions (Table 2).

Table 1
HRV variables in the Time Domains (ms) of Frequency (n.u.) in three Wods

	Fran	Megan	Diane	Fran	Megan	Diane
		RMSSD			LF	
Pre	49.8±32.1	49.8±19.4	54.7±27.1	76.3±4.2	72.6±12.8	68.0±10.8
During	12.0±16.7	5.5±3.2	4.4±0.8	55.1±18.8	42.3±15.9	73.7±15.2
Imed After	7.1±4.5	6.7±3.0	6.9±4.3	74.6±13.8	78.1±4.9	80.9±9.4
Post 1	8.6±4.0	6.8±3.9	7.2±4.2	78.8±11.8	83.8±10.1	87.5±9.7
Post 2	13.7±12.8	8.1±5.1	12.7±5.7	87.5±4.9^{+}	90.0±4.3^{+}	87.9±7.4^{+}
Post 3	13.9±5.9^{++}	15.7±9.3^{++}	22.9±7.6^{++}	82.0±8.6^{++}	89.2±3.4^{++}	86.1±4.9^{++}
Post 4	27.5±14.6^{+++}	22.1±13.6^{+++}	29.1±11.6^{+++}	79.9±11.7^{+++}	81.7±9.1^{+++}	81.6±7.7^{+++}
Effect Size		0.08 Trivial			0.12 Trivial	
		STDRR			HF	
Pre	54.9±26.6	57.7±13.6	58.2±21.7	23.5±4.1	27.3±12.6	31.8±10.8
During	10.2±15.5	4.1±2.3	4.1±1.2	44.5±18.6	57.1±15.7	25.9±15.0
Imed After	6.7±3.2	7.7±4.2	9.4±5.2	25.2±13.6	21.4±4.7	19,0±9.3
Post 1	11.2±6.7	10.3±6.6	11.6±7.1	21.0±11.7	16.1±10.0	12.4±9.6
Post 2	18.9±13.4^{+}	15.2±7.1^{+}	24.3±8.8^{+}	12.4±4.9^{+}	10.0±4.3^{+}	12.1±7.4^{+}
Post 3	21.5±7.7^{++}	25.8±14.0^{++}	34.8±10.3^{++}	18,0±8.6	10.8±3.3	13.9±4.9
Post 4	38.4±15.7^{+++}	32,0±13.6^{+++}	44.3±16.2^{+++}	20.0±11.7	18.3±9.1	18.2±7.8
Effect Size		0.15 Trivial			0.10 Trivial	
		pNM50			LF/HF	
Pre	22.4±20.4	25.1±16.8	86.9±49.4	3388.1±938.9	3440.2±2076.4	2565.6±1481.5
During	3.9±10.9	0.0±0.1	0.0±0.1	1526.2±1699.7	423.5±837.6	4331.5±3655.0
Imed After	0.4±0.9	0.0±0.1	0.8±2.1	4344.2±3133.4	3744.5±1197.5	5604.5±6676.2
Post 1	0.1±0.2	0.2±0.42	0.4±0.7	5270.2±3356.2	7151.2±4521.1	9785,0±4539.3
Post 2	0.9±1.6	0.3±0.59	5.4±6.9	7721.4±2093.8	10935,0±5895.2	8923.8±3354.6
Post 3	1.1±1.4	2.8±4.98	15.1±12.0	6046.4±3924.1	9179.4±3399.1	7514.5±4756.8
Post 4	4.6±5.1	23.0±53.71	31.5±28.4	5055,0±2503.6	6426.4±5430.4	5145.1±2091.2
Effect Size		0.12 Trivial			0.18 Trivial	

Values are means ± standard deviations; at rest (Pre); during exercise (During); immediately after the last exercise (Imed After); 15 minutes after the last exercise (Post 1); 30 minutes after the last exercise (Post 2); 45 minutes after the last exercise (Post 3); and 60 minutes after the last exercise (Post 4). $^{+}$Pre vs. Post 2; $^{++}$Pre vs. Post 3; $^{+++}$Pre vs. Post 4; *Post 1 vs. Post 2; **Post 1 vs. Post 3; $^{\#}$Post 1 vs. Post 4; $p<0.05$.

In the time domain, STDRR showed no differences in all WODs (p <0.16) but there was a significant Time effect (p <0.001) when the interaction between WOD*Time was applied.

The data related to RMSSD when compared with baseline, showed a significant effect of Time at several moments: Imed After, Post 1, Post 2, Post 3 and Post 4. The RMSSD showed no significant reduction in Fran (p< 0.40), Megan (p < 0.23) and Diane (p < 0.18). However, when considering the interaction between WOD*Time the results demonstrated that there was no differences (p <0.73). The magnitude of the ES was trivial (ES <0.08).

The values of pNN50 showed that Time (p = 0.00) significantly interfered with HRV but the same did not occur when the analysis considered different WODs (p < 0.65) nor the interaction between WOD*Time (p < 0.73), with ES being low (0.58). The LF showed a significant difference (p < 0.001) in the comparison between WODs and Time and in interaction also showed significant differences (F = 3.55; ES = 0.12) during exercise and between Diane and Megan. When considering the LF / HF relationship a significant differences between Fran and Megan WODs were evident (p < 0.001).

Table 2
Hemodynamic Variables in three WODs

	Fran	Megan	Diane	Fran	Megan	Diane
		SBP			DBP	
Pre	126.2±20.2	123.7±18.4	126.4±21.7	83.3±6.4	81.7±7.1	84.4±7.0
Imed After	126.8±21.9	123.8±19.8	126.7±23.4	83.5±6.7	81.6±7.4	84.6±7.4
Post 1	117.3±23.4	115.2±9.6	117.1±14.1	81.2±5.0	79.0±5.7	82.5±6.6
Post 2	105.8±23.9	105.3±15.7	104.4±15.6	79.9±4.4	77.8±5.3	81.7±7.00$^{+,*}$
Post 3	99.3±22.0^{++}	100,0±15.5^{++}	100.8±15.4^{++}	79.2±4.9	77.9±5.8	79.8±5.6**
Post 4	92.6±20.2^{+++}	92.8±14.6^{+++}	93.0±12.1^{++}	77.2±5.0	78.4±4.7	78.4±5.2$^{\#}$
Effect Size		0.18 Trivial			0.06 Trivial	

Values are means ± standard deviations; at rest (Pre); immediately after the last exercise (Imed After); 15 minutes after the last exercise (Post 1); 30 minutes after the last exercise (Post 2); 45 minutes after the last exercise (Post 3); and 60 minutes after the last exercise (Post 4); $^{+}$Pre vs. Post 2; $^{++}$Pre vs. Post 3; $^{+++}$Pre vs. Post 4; *Post 1 vs. Post 2; ** Post 1 vs. Post 3; $^{\#}$Post 1 vs. Post 4; p<0.05.

Regarding DBP, the WOD*Time interaction was not significant (p < 0.20, ES = 0.06) while in SBP increased immediately after exercise (p < 0.05; ES = 0.18) in relation to other measurements at all three WODs. Moreover, Diane showed differences between Pre vs. Post 2 (p < 0.03), between Post 1 vs. Post 2 (p < 0.01), between Post 1 vs. Post 3 (p < 0.02) and between Post 1 vs. Post 4 (p < 0.02).

Discussion

The aim of this study was to verify the acute response of heart rate variability and blood pressure during and after three of CrossFit® workouts. The main findings of this research showed that: a) all three WODs (Fran, Megan, Diane) promote significant reductions in HRV through parasympathetic indicators (RMSSD, HF) and increased activity of the sympathetic activity (LF, LF / HF); b) significant reductions in BP values were present regardless of the type of the session; c) there was no significant difference between WODs in both HRV and BP.

Sympathetic activity remained high throughout the 60 minutes of recovery. There was an inversion in the proportion of the LF and HF bands due to the metabolic need to continue the exercise, this may have been the main cause for this increase in sympathetic activity (Nóbrega *et al.,* 2014), a response that was evidenced in all WODs. The reduction in parasympathetic activity (HF-nu) occurred in all WODs significantly. Although effect size data (ES) proved to be of great (large) magnitude, both in the HF (nu) and LF (nu) indexes post-exercise moments and also in the RMSSD index (moderate ES) after performing the Diane WOD. This response may be due to the combination of exercises in this WOD, which includes lifting free weights followed by handstand push-up, this last exercise is performed in an inverted position increasing the metabolic demand to maintain performance (White & Raven, 2014).

Kliszczewicz *et al.* (2014) showed that heart rate response in Cindy WOD reached values between 76.0% to 96.0% of peak heart rate and this response would be caused primarily by parasympathetic withdrawal and an increase in sympathetic activity. The variation in the RMSSD index has a higher correlation with volume than the intensity (Holmes *et al.,* 2018). Thus, the smaller this variation, the greater the parasympathetic activity and the ability to withstand the exercise stress, a factor that is linked to the level of physical conditioning (Hernández-Cruz *et al.,* 2022). In intermittent exercises, as in CrossFit® and in short duration tests, the autonomic modulations change according to the intensity, suggesting that a low number of repetitions at moderate to intense loads would be the main factors for cardiovascular stress. Furthermore, the added tension time provided by the continuous execution of two or more exercises in a circuit mode, as typical in CrossFit®, have a more expressive effect in the HRV response (Paz *et al.,* 2013), supporting our findings.

Figueiredo *et al.* (2015) compared the effect of 1, 3 and 5 sets in a strength training session on SBP, DBP and HRV. The results showed that the post-exercise hypotensive effect is dependent on the training volume and the high volume of training influenced the HRV response, observed by the reduction of the parasympathetic system through the mean values of HF and RMSSD index, which were more significant when the subjects performed 5 sets.

The high volume can generate a cardiovascular imbalance due to changes in plasma volume, cardiac output and stroke volume. In addition, a high volume of training, as in CrossFit® sessions, promotes greater recruitment of motor units, which requires greater activity of the sympathetic nervous system and greater activation of metaboreceptors, mechanoreceptors and baroreflexors induced by the mechanical occlusion of blood flow (Dantas *et al.,* 2018).

CrossFit® is also capable of inducing the hypotensive effect, regardless of the format of the training session. As in the present study, Tibana *et al.* (2017) did not observe any interaction between SBP–and DBP responses in two different training sessions, and also found that DBP remained lower than the resting values. Paz *et al.* (2013) suggest that the heart inotropism observed in trained subjects, at different recovery intervals, generates baroreflex stimulation, left ventricular pressure receptors and carotid bulb receptor that causes vagal afferent stimulation and activation of the parasympathetic branch of the autonomic nervous system. Figueiredo *et al.* (2016) showed that shorter recovery intervals induce a hypotensive effect after exercise which is significantly associated with a greater reduction in HRV, being demonstrated by the significant increase in withdrawal of parasympathetic activity when comparing baseline values and post-exercise. This hypotensive effect is associated with cardiac output, which is not compensated by the reduction in peripheral vascular resistance and the increase in sympathetic modulation. This supports our study in which SPB showed a significant reduction in both protocols, however, without significant difference between them. The fact that individuals are trained could interfere in the accumulation of metabolites and activated the dependent nitric oxide pathways favouring a greater reduction in BP (Figueiredo *et al.,* 2014).

This study had some limitations: size and experience of the sample; and daily nutrition was not controlled. These results can be used by trainers and coaches to prescribe new training sessions, however variables such as volume, intensity and type of exercise performed interfere in the autonomic modulation. For future studies, it would be important to monitor the HRV response after training sessions for a longer period of time, such as 24 and 48 hours, with larger sample size and evaluation of subjects of different age, gender and conditioning level, in order to control the return of vagal activity to pre-exercise values.

Conclusion

All three CrossFit® WODs changed autonomic nervous system activity with a reduced HRV and HPE, regardless the number of exercises included (2 vs. 3 exercises). We conclude that different types of CrossFit® workouts do not imply different stimulus in the autonomic response terms. Therefore, coaches can maintain a large variation of WODs without impairing the positive autonomic nervous system effects.

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