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ORIGINAL ARTICLE

A short set configuration attenuates the cardiac parasympathetic withdrawal after a whole-body resistance training session

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Abstract

Purpose We aimed to analyse the acute effects of set configuration on cardiac parasympathetic modulation and blood pressure (BP) after a whole-body resistance training (RT) session.

Methods Thirty-two participants (23 men and 9 women) performed one control (CON) and two RT sessions differing in the set configuration but with the same intensity (15RM load), volume (200 repetitions) and total resting time (360 s between sets for each exercise and 3 min between exercises): a long set configuration (LSC: 4 sets of 10 repetitions with 2 resting minutes) and a short set configuration session (SSC, 8 sets of 5 repetitions with 51 resting seconds). Heart rate variability, baroreflex sensitivity, the low frequency of systolic blood pressure oscillations (LFSBP), BP and lactatemia were evaluated before and after the sessions and mechanical performance was evaluated during exercise.

Results LSC induced greater reductions on cardiac parasympathetic modulation versus SSC after the session and the CON ($p < 0.001$ to $p = 0.024$). However, no LFSBP and BP significant changes were observed. Furthermore, LSC caused a higher lactate production ($p < 0.001$) and velocity loss ($p \leq 0.001$) in comparison with SSC.

Conclusion These findings suggest that SSC attenuates the reduction of cardiac parasympathetic modulation after a whole-body RT, improving the mechanical performance and decreasing the glycolytic involvement, without alterations regarding vascular tone and BP.

Keywords Cardiac autonomic control · Baroreflex sensitivity · Set configuration · Resistance exercise

Abbreviations

15RM	15-Repetition maximum load
5LFR	Last five to the first five repetition velocity ratio
BEI	Baroreflex effectiveness index
BP	Blood pressure
BPV	Blood pressure variability
BPR	Bench press
BRS	Baroreflex sensitivity
CON	Control session
DBP	Diastolic blood pressure
HF	High frequency in absolute values
HFn.u.	High frequency in normalised units
HR	Heart rate
HRV	Heart rate variability
KE	Knee extension
LFSBP	Low frequency of systolic blood pressure
LSC	Long set configuration session
Lt	Capillary blood lactate concentration
MAP	Mean arterial pressure
MMR	Average mean propulsive velocity to maximum velocity ratio
MPV	Mean propulsive velocity
PI	Pulse interval
RMSSD	Root mean square of differences between adjacent pulse interval
RT	Resistance training
RTE	Relative treatment effect

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SBP	Systolic blood pressure
SDNN	Standard deviations of normal-to-normal pulse intervals
SQ	Parallel squat
SSC	Short set configuration session

Introduction

The autonomic nervous system, through the "paired antagonistic innervation", i.e. sympathetic and parasympathetic activity (Hess 2014), is responsible for the cardiovascular response to ensure the physiological demands and maintain the cardiovascular homeostasis. Several feedback and feedforward mechanisms, moderated by central and peripheral neural structures, are involved to induce these responses (Fisher et al. 2015). Despite the contradictory viewpoints regarding the markers of autonomic regulation (Eckberg 1997; Billman 2011; Parati et al. 2006), currently some non-invasive methods allow evaluating them. Heart rate variability (HRV) and baroreflex sensitivity (BRS) are indicators of cardiac parasympathetic activity (Malik 1996; Ogoh et al. 2005). HRV provides information about the integrated activity of the parasympathetic nervous system over time (Rosenwinkel et al. 2001), whereas BRS indicates how efficiently the cardiac baroreflex is able to adapt the following heartbeats in response to changes in systolic blood pressure (SBP) (Stuckey et al. 2012), evaluating the ability of the parasympathetic system to respond reflexively to a discrete stimulus. Additional information regarding sympathetic vasomotor tone can be estimated assessing the low frequency of systolic blood pressure oscillations (LFSBP), which is closely associated with arterial stiffness (Bruno et al. 2012) and may reveal the activity of sympathetic outflow (Pagani et al. 1986; Malliani et al. 1991).

Resistance training (RT) is currently recommended as a significant component of a healthy fitness lifestyle and as a means of prevention for several diseases (Pollock et al. 2000). However, paradoxically after an RT session, the risk of suffering a cardiac event increases in apparently healthy individuals (Goodman et al. 2016) and especially in people with elevated cardiac risk (Albert et al. 2000), due to the reductions in cardiac autonomic modulation (Rosenwinkel et al. 2001). Several investigations have studied the acute effect of RT on cardiac autonomic modulation (Rezk et al. 2006; Heffernan et al. 2008; Kingsley et al. 2014), cardiac baroreflex (Heffernan et al. 2007, 2008; Niemelä et al. 2008) and vascular tone (Queiroz et al. 2015; Kingsley et al. 2019). Whilst the acute effects of RT on vascular tone remain unclear, the review by Kingsley and Figueroa (2014) summarised that RT induces a parasympathetic withdrawal after exercise, with the consequent increased risk of suffering a cardiac event as previously mentioned. To reduce this elevated risk of suffering a cardiac event, the loading parameters of the RT session should be properly selected to minimise the cardiac parasympathetic withdrawal. In this regard, a limited load intensity (Niemelä et al. 2008; Lima et al. 2011), a small volume (Figueiredo et al. 2015a) or an adequate rest interval length (Figueiredo et al. 2016) may reduce this loss. In addition, the set configuration is another loading parameter that may attenuate the reductions of cardiac parasympathetic modulation after a session of RT (Mayo et al. 2015, 2016). Set configuration refers to the number of repetitions performed in each set in relation to the maximum number of feasible repetitions of such set (Iglesias-Soler et al. 2014b). Short set configurations, with a low intensity of effort (Steele 2014), produce smaller reductions on the cardiac autonomic modulation (Iglesias-Soler et al. 2014a) and cardiac baroreflex (Mayo et al. 2015, 2016) in comparison with long set configurations, close to, or leading to muscular failure, which may result in a higher reduction in mechanical performance (Latella et al. 2019). Moreover, short sets produce a non-significant, or slight glycolytic involvement, in comparison with long sets (Iglesias-Soler et al. 2012; Rial-Vázquez et al. 2020), whilst allowing comparable or greater gains in strength (Oliver et al. 2013; Iglesias-Soler et al. 2015). Since the relationship between the glycolytic involvement and the parasympathetic withdrawal was observed previously both during exercise (Buchheit et al. 2007) and when it is injected intravenously at rest (George et al. 1989; Yeragani et al 1994, 1996), short sets may be a unique strategy to promote health benefits whilst reducing the possible adverse effects of the transient reductions in cardiac parasympathetic modulation (Albert et al. 2000). Nevertheless, previous studies analysing the set configuration on cardiac autonomic modulation and cardiac baroreflex have used a one-exercise model (Iglesias-Soler et al. 2014a; Mayo et al. 2015, 2016) This one-exercise model does not accurately reflect the conventional and suitable RT session, performing several upper- and lower-body RT exercises (American College of Sports Medicine 2009). Thus, it is important to expand on the current body of literature using more than one resistance exercise.

On the other hand, concomitant with the transient reduction in cardiac parasympathetic modulation there may be an acute decrease in blood pressure (BP) after an RT session. For this reduction to occur, the session needs to meet some characteristics, such as an medium intensity of load (Rezk et al. 2006; Figueiredo et al. 2015b; Neto et al. 2016), enough volume within session (Simão et al. 2005; Figueiredo et al. 2015a), the onset of muscular failure (De Souza et al. 2013), or exercises that involve enough muscle mass (Polito and Farinatti 2009; Mohebbi et al. 2016). Nevertheless, it remains unclear if the magnitude of this effect can be modulated by the interaction of different loading parameters (Casonatto et al. 2016). In this regard, studies analysing the effects of set configuration on the postexercise BP are scarce, showing mixed results regarding the hypotensive effect of different configurations (Mayo et al. 2015, 2016). In this sense, to the best of our knowledge, the postexercise BP after different set configuration sessions has only been studied by a single-exercise model (Mayo et al. 2015, 2016) but not for routines composed by several RT exercises involving major muscle groups.

Therefore, we aimed to compare the effect of two different whole-body RT set configuration protocols (long versus short set configuration) on the cardiac parasympathetic modulation, vascular tone and postexercise BP response. We hypothesised that a short set configuration session would attenuate the reduction on cardiac parasympathetic activity in comparison with a long set configuration, showing lower neuromuscular fatigue and a reduced glycolytic involvement. Our second hypothesis was that there would not be differences between set configurations regarding the vascular tone and BP response after whole-body RT sessions.

Methods

Participants

Thirty-two apparently healthy individuals (23 men and nine women) with self-reported previous experience of at least 6 months with RT participated in this cross-sectional study. The participants were screened and excluded if they had a prior history of cardiovascular disease, any medical contraindications for lifting weights, or were using any controlled medication. This study was approved by the local Institutional Ethics Committee, and the participants read and signed an informed consent form.

Study design

The participants visited the laboratory a total of six times separated at least by 72 h. The first and second sessions were conducted to familiarise the participants with the resistance exercises. In the third session, 15-repetition maximum load (15RM) was determined for all exercises. After assigning the participants into different experimental sequences, following a randomised block design in order to warrant an equivalent regarding the sex distribution, the final three sessions consisted of two experimental [long (LSC) and short (SSC) set configuration] and one control (CON) protocols. Participants were assessed before and after each session for cardiovascular and metabolic variables. In addition, mechanical performance was collected during some exercises. A schematic representation of the study is presented in Fig. 1.

The experimental sessions were composed of five resistance exercises performed in the same order: knee extension (KE), leg curl, lateral pull-down, bench press (BPR), and parallel squat (SQ). Guided machines were used for performing the KE (Technogym, Gambettola, Italy), leg curl, and lateral pull-down (Biotech Fitness Solutions, Brazil) exercises, whereas BPR and SQ were performed on a Smith Machine (Telju Fitness, Toledo, Spain). Participants were encouraged to produce the maximal intended velocity during the concentric phase of the exercises and to complete the full range of movement for each repetition of each exercise.

Familiarisation sessions

In the familiarisation sessions, the participants were instructed on how to perform each resistance exercise. In this regard, the individual position references for each exercise were registered to standardise the execution conditions across the study. The full range of each exercise was objectively determined by the investigator for all exercises, excepted for SQ, which was controlled by placing an adjustable bench at the height required to achieve a parallel squat.

The first session started with a 5-min warm-up in a cycle ergometer at 60–80 revolutions per min (Monark 828E; Monark Exercise AB, Vansbro, Sweden) as well as joint mobilisation, followed by 2 sets of 15 repetitions with approximately 50% of perceived maximum load and 2 min of recovery between sets and exercises. In addition, height was measured by a stadiometer (Seca 202; Seca Ltd., Hamburg, Germany), body mass measured with an electronic scale (Omron BF-508, Omron Healthcare Co., Kyoto, Japan) and body mass index was calculated. In the second session, participants were instructed to perform the same warm-up, joint mobilisation and 2 sets at 75% of perceived maximum load. In the last set of each exercise, participants were encouraged to perform the maximal number of repetitions, to get more experience reaching muscular failure.

15RM test

In the third session, the 15RM test was conducted to assess the maximum load that each participant could lift no more than 15 times for each exercise using correct form and technique. The session started with the general warm-up previously described, followed by 10 repetitions of each exercise performed at 50% of the load from the last set of the familiarisation session. Then, after 5 min of rest, participants performed a set with approximately 110% of the load from the last set of the familiarisation session. If participants performed 16 repetitions, the load was increased, whereas if they could not complete 15 repetitions, the load was reduced. The first load which they performed no more than 15 repetitions was considered the 15RM. The test comprised a maximal of 2 attempts interspersed with at least 5 min rest. Participants were instructed to perform the concentric portion

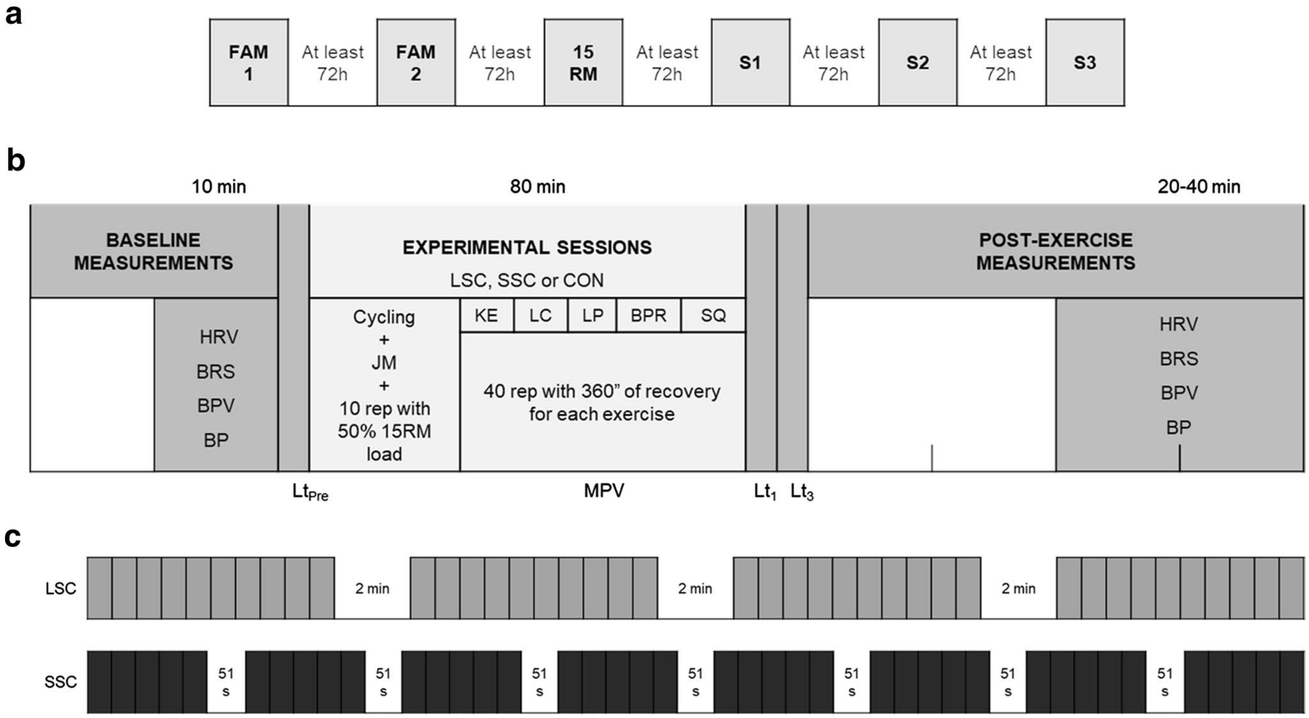


Fig. 1 **a** Schematic representation of the study. *FAM* familiarisation session, *S* experimental session. **b** Graphical simplification assessment. *LSC* long set configuration session, *SSC* short set configuration session, *CON* control session, *HRV* heart rate variability, *BRS* baroreflex sensitivity, *BPV* blood pressure variability, *BP* blood pressure, *Lt* Capillary blood lactate concentration, *MPV* mean propulsive velocity, *JM* joint mobilisation, *KE* knee extension, *LC* leg curl, *LP* lateral pull-down, *BPR* bench press, *SQ* parallel squat. **c** Representation of the experimental sessions. All sessions consisted of 40 repetitions and 360 s of total rest with the 15RM load for each exercise and with 3 min of rest between exercises. LSC: 4 sets of 10 repetitions with 2 min of rest between sets. SSC: 8 sets of 5 repetitions with 51 s of rest between sets

of each repetition as fast and explosive as possible. Muscle failure was defined when the participants could not complete the full range of movement of the exercise or the load could not be moved. The order of the resistance exercises was the same as we previously described.

Experimental sessions

Each participant completed the two experimental sessions (LSC and SSC) and the CON in random order. In all sessions, the participants were instructed to refrain from alcohol, and caffeine for 3 h and exercise for 24 h prior to the testing sessions, and keep hydration and feeding habits stable. Participants were tested in the postprandial state (3 h) upon arrival to the laboratory. Sessions were separated by at least 72 h and were performed at the same time of the day (± 1.5 h) in a temperature and humidity-controlled room (23 °C and 50% respectively). Both experimental sessions entailed performing a total of 200 repetitions (40 per exercise) with the 15RM load and with a total rest of 42 min (360 s between sets for each exercise and 3 min between exercises) but differing in the set configuration. LSC consisted on 4 sets of 10 repetitions (i.e. an intensity of effort of 66%, 10 out of 15RM) with 2 min of rest between sets and 3 min between exercises. SSC consisted of 8 sets of 5 repetitions (i.e. an intensity of effort of 33%, 5 out of 15RM) with a rest of 51 s between sets and 3 min between resistance exercises. After a baseline assessment, and before both LSC and SSC, the general warm-up previously described was performed. In addition, before each exercise, a specific warm-up consisting of 10 repetitions with 50% of 15RM was carried out. In CON, before and after the measurements, the participants remained seated in the laboratory for 80 min without performing any resistance exercise.

Procedures

Physiological recording

Cardiovascular parameters were registered using the Task Force® Monitor (CNSystems, Graz, Austria). A three-lead electrocardiogram obtained a continuous heart rate (HR) with a sampling frequency of 1000 Hz. Beat-by-beat monitoring of SBP, diastolic blood pressure (DBP), and mean arterial pressure (MAP) were obtained by photoplethysmography. The finger cuffs were placed on the proximal phalange of the index and the middle fingers of the right hand, sited on the fourth intercostal space. The absolute values of the finger pressure were automatically and continuously transformed into values of braquial artery by an oscillometric device. It consisted of an arm cuff tightly attached to the left arm with the compressed air outlet on the brachial artery and the lower edge of the cuff approximately 2.5 cm from the elbow crease. Considering the delay caused by the cardiovascular device colocation and calibration procedures, and to allow the comparability with previous resistance exercise studies using similar epochs, cardiovascular data were obtained 10 min before the sessions and 20 min after the end of the protocols (i.e. in the period 20–40 min). During this time, participants were lying in the supine position on a stretcher in a quiet room, breathing with a respiratory rate of 0.2 Hz (12 breaths per min) to avoid the effect of respiratory rate on HRV measures (Penttila et al. 2001). Participants were asked not to move or speak during the measurements. (Laborde et al. 2017).

Capillary blood lactate concentration (Lt) was obtained using a portable blood lactate analyser with a sample analysis time of 15 s and a required blood sample of 0.5 µL (Lactate Scout, SensLab GmbH, Germany). Lactate Scout uses an enzymatic-amperometric method for the detection of lactate in capillary blood and his reliability has been previously evaluated (Tanner et al. 2010). Data were obtained immediately before, and 1 and 3 min after each experimental session.

Mechanical recording

The mean propulsive velocity (MPV) of every repetition was recorded with a linear velocity transducer (T-Force System, Ergotech, Murcia, Spain). Validity and reliability of this device have been previously reported (Sánchez-Medina and González-Badillo 2011). MPV consisted of the mean velocity during the propulsive phase of the exercise, that is, the portion of the concentric period in which the barbell acceleration is greater than the acceleration due to gravity (Sánchez-Medina et al. 2010). MPV was registered for three exercises: KE, BPR, and SQ.

Data analysis

HRV was used to assess the autonomic modulation of the heart. Analysis of the data consisted of time- and frequency-domain analysis. The time-domain analysis included the standard deviations of normal-to-normal pulse intervals (PI) of the HR (SDNN), a measure of global autonomic control, and the root mean square of differences between adjacent PI (RMSSD), a measure of parasympathetic activity. For the spectral analysis of HRV, Fast Fourier Transformation method was employed. High-frequency power (0.15–0.4 Hz) in absolute values (HF) and normalised units (HFn.u.) was calculated for estimating cardiac parasympathetic activity. The data analysis was performed for the last 5 min of the period of 10 min before the beginning of the session (baseline) and 5 min epochs during the 20–40 min period after the session, since epochs of 5 min are recommended when taking short-term recordings (Malik 1996). Automatic artefact correction (i.e. medium correction threshold level, ± 0.25 s) and calculation of HRV values were obtained using the Kubios HRV software v2.1 (The Biomedical Signal and Medical Imaging Analysis Group, Department of Applied Physics, University of Kuopio, Finland). The data were detrended with the smooth priors method. The Lambda value was fixed at 500. The mean artefact correction of the signal was 1.04 ± 2.53%. In addition, HR values were recorded as a reflection of cardiac autonomic activity and as an independent predictor of sudden cardiac death risk (Hjalmarson 2007).

BRS, quantified by the sequence method, was employed to estimate the effect of the sessions on the cardiac baroreflex. This method is based on the identification of sequences of three or more consecutive beats in which SBP and the PI increase progressively (+PI/+SBP) or fall (−PI/−SBP) in a linear fashion (Bertinieri et al. 1988). In specific, the sequences of three or more beats for which SBP and PI of the next beat (Lag 1) changed in the same direction (Blaber et al. 1995) were analysed. The threshold change was defined asr 1 mmHg for BP and 6 ms for PI. BRS analysis included the total number of detected sequences (BRS_{count}), the mean slope of such sequences (BRS_{slope}), and the ratio between the number of SBP ramps followed by the respective reflex PI ramps and the total number of SBP ramps observed in a given time window, known as the baroreflex effectiveness index (BEI) (Rienzo et al. 2001). BEI reflects the number of times the baroreflex is active in controlling the HR in response to BP oscillations, which is indicative of the severity and duration of several diseases, such as renal failure (Johansson et al. 2007). For BEI, only 24 participants were analysed.

Blood pressure variability (BPV) was used to estimate the sympathetic vasomotor tone. Our BPV analysis consisted of spectral analysis of SBP variability. The autoregressive spectral method was used, and the low-frequency activity (0.04–0.15 Hz) in absolute values was calculated (LFSBP) (Pagani et al. 1997).

Data recordings of BRS and BPV were performed for the last 10 min before the protocols (baseline) and for the intervals 20–30 and 30–40 min after each session. Epochs of 10 min are usually used to analyse BRS after resistance exercise (Niemelä et al. 2008; Queiroz et al. 2015). BRS and BPV data were obtained using TFM software v2.3 (CNSystems, Graz, Austria) (Fortin et al. 2001).

For BP analysis, the beat-to-beat responses registered before (baseline) and after the sessions were analysed in epochs of 10 min. The percentage change of SBP, DBP, and MAP was calculated for all the participants. Percentages changes were calculated as follows: Δ%30-Baseline = (value of the 20–30 epoch − value of baseline)/value of baseline; Δ%40-Baseline = (value of the 30–40 epoch − value of baseline)/value of baseline. Percentage changes were used to represent the differences in BP values. For measurements obtained with a photoplethysmography device, the responses to exercise in percentage changes have been previously validated and well correlated with simultaneous invasive procedures, being these non-invasive measurements a very sensitive method to follow rapid changes in arterial pressure (Gomides et al. 2010).

Regarding Lt, the maximum value of the two post-test measurements was selected, and the percentage change of lactatemia (Δ%Lt) was calculated in both training sessions.

MPV was used to estimate the neuromuscular fatigue of each session. The MPV of every repetition was calculated and averaged in both experimental sessions for KE, BPR, and SQ. Thereafter, other parameters were calculated for comparing the loss of mechanical performance between sessions. For the overall maintenance of velocity analysis, the mean to maximum MPV ratio of each session (MMR) was calculated as follows: ([average MPV/maximum MPV] × 100) (refs). Values near 100% imply less velocity loss. For quantifying the velocity loss throughout the sessions, the last five to the first five repetition ratio (5LFR) was obtained. For this calculation, the mean MPV of the last five repetitions and the first five ones were considered as follows: 5LFR = ([(average last five repetitions MPV/average first five repetitions MPV) − 1] × 100). Lower values imply higher magnitudes of velocity loss and positive values was interpreted as velocity gains.

Statistical analysis

Descriptive parameters are shown as means ± standard deviation. Normality was tested using the Shapiro–Wilk test. The characteristics of participants were compared between sexes using independent sample *t* test or Mann Whitney *U* test, respectively. As all physiological variables violated the assumption of normality and a logarithmic transformation was not possible, a nonparametric ANOVA type test was employed using the nparLD R software package (Noguchi et al. 2012) for evaluating the main effects and interactions between sex (men, women), sessions (LSC, SSC, and CON) and times (Baseline, 20–25, 25–30, 30–35, and 35–40 for HRV and HR parameters; Baseline, 20–30 and 30–40 min for BRS and LFSBP; and %30-Baseline and Δ%40-Baseline of SBP, DBP, and MAP). Since gender did not interact with the rest of factors (i.e. time and session), a two-way nonparametric ANOVA type test was performed with pooled data from men and women. If a significant interaction was detected, paired comparisons were performed using the Wilcoxon signed-rank test with Bonferroni correction. For main effects' interpretation, relative treatment effect (RTE) was considered. RTE has a value between 0 and 1 and indicates the probability that a measurement in one group at a given time-period is larger than a value of this variable in any other combination of group and time (Schild et al. 2016).

For capillary lactate production, Wilcoxon signed-rank test was performed to analyse the delta differences between experimental sessions (Δ%Lt). For mechanical responses, paired *t* tests and Wilcoxon signed-rank test were used for analysing differences between sessions. Furthermore, training effect size was reported using Hedge's *g* (*g*) and Matched Pair Rank Biserial Correlation (*r*) for parametric and nonparametric contrasts, respectively. Matched Pair Rank Biserial corresponds to the difference between the proportions of positive and negative ranks (Kerby 2014).

R software v3.6.1. (R Foundation, Vienna, Austria), GraphPad Prism 5.01 (GraphPad Software, San Diego, CA, USA), Comprehensive Meta-Analysis v.2 (Biostat Inc., Englewood, NJ, USA), and IBM SPSS v.20.0. (IBM Corp, Armonk, NY, USA) were used for statistical analysis. Statistical significance level was set at 0.05.

Finally, a post-hoc power analysis was calculated using the G Power software (version 3.1.9.2). The statistical power ($1-\beta$) of a repeated measures ANOVA with 3 and 5 measurements for a sample size of 32, and a correlation among repeated measures of 0.5 and a medium effect size ($f = 0.25$) are 0.87 and 0.96, respectively.

Results

The characteristics of participants are summarised in Table 1. Men and women were matched for age and body mass index; however, men showed higher weight, height, and 15RM values for all exercises than women.

For HR, main effect of session ($p < 0.001$; RTE: 0.629, 0.598, and 0.273 for LSC, SSC, and CON, respectively), time ($p < 0.001$; RTE: 0.378, 0.542, 0.540, 0.530 and 0.510 for Pre, 20–25, 25–30, 30–35, and 35–40, respectively), and a session by time interaction were detected ($p < 0.001$). Post-hoc analyses (Fig. 2a) showed higher values for all post-test epochs in LSC and SSC versus baseline ($p < 0.001$) and versus CON ($p < 0.001$). Furthermore, LSC data were higher in comparison with SSC during all the postexercise epochs ($p < 0.001$ to 0.006).

For SDNN, main effects for session ($p = 0.004$; RTE: 0.416, 0.498, and 0.585 for LSC, SSC, and CON, respectively), time ($p < 0.001$; RTE: 0.585, 0.451, 0.490, 0.476; and 0.498 for Baseline, 20–25, 25–30, 30–35, and 35–40,

Table 1 Physical and functional characteristics of the participants ($n = 32$)

	Men ($n = 23$)	Women ($n = 9$)	Total ($n = 32$)	p value
Age (years)	23 ± 2	24 ± 3	23 ± 2	0.456^{+}
Weight (kg)	73.14 ± 8.45	62.11 ± 6.37	70.04 ± 9.30	$< 0.001^{*}$
Height (cm)	1.76 ± 0.06	1.65 ± 0.06	1.73 ± 0.08	$< 0.001^{*}$
BMI (kg/m^2)	23.64 ± 2.03	22.72 ± 1.93	23.38 ± 2.01	0.402^{+}
15RM in KE (kg)	79 ± 13	55 ± 10	72 ± 16	$< 0.001^{*}$
15RM in LC (kg)	54 ± 9	38 ± 9	50 ± 11	$< 0.001^{*}$
15RM in LP (kg)	49 ± 8	34 ± 5	45 ± 10	$< 0.001^{*}$
15RM in BPR (kg)	51 ± 12	29 ± 5	45 ± 14	$< 0.001^{*}$
15RM in SQ (kg)	80 ± 19	55 ± 10	73 ± 20	0.001^{*}

Values represent means ± SD

BMI body mass index, *KE* knee extension, *LC* leg curl, *LP* lateral pull-down, *BPR* bench press, *SQ* parallel squat

$^{*}p$ values are derived from independent sample t test and ^{+}p values are derived from Mann–Whitney U test

respectively), and an interaction of session by time were detected ($p = 0.025$). Post-hoc pairwise comparisons are shown in Fig. 2b. Lower values were revealed after both experimental sessions in comparison with the CON ($p < 0.001$). Nevertheless, lower values of SDNN at the 35–40 epoch were observed only after LSC with respect to the baseline ($p < 0.001$). During all the postexercise measures, LSC showed lower SDNN values in comparison with SSC ($p = 0.001$–0.024).

For RMSSD, neither a main effect of session ($p = 0.238$; RTE: 0.457, 0.533, and 0.520 for LSC, SSC, and CON, respectively) nor time ($p = 0.070$; RTE: 0.578, 0.481, 0.474, 0.484, and 0.483 for baseline, 20–25, 25–30, 30–35, and 35–40, respectively) was detected, whereas a significant session by time interaction was observed ($p = 0.013$). For LSC and SSC, RMMSD values after exercise were always lower in comparison with the baseline ($p < 0.001$–0.002) and CON values ($p < 0.001$). Furthermore, all post-training records were significantly lower in LSC when compared with SSC ($p < 0.001$–0.004) (Fig. 2c).

Regarding absolute HF values, neither a main effect of session ($p = 0.498$; RTE: 0.484, 0.496, and 0.520 for LSC, SSC, and CON, respectively) or time ($p = 0.883$; RTE: 0.480, 0.486, 0.503, 0.510, and 0.520 for baseline, 20–25, 25–30, 30–35, and 35–40, respectively), nor session by time interaction was found ($p = 0.687$) (Fig. 2d).

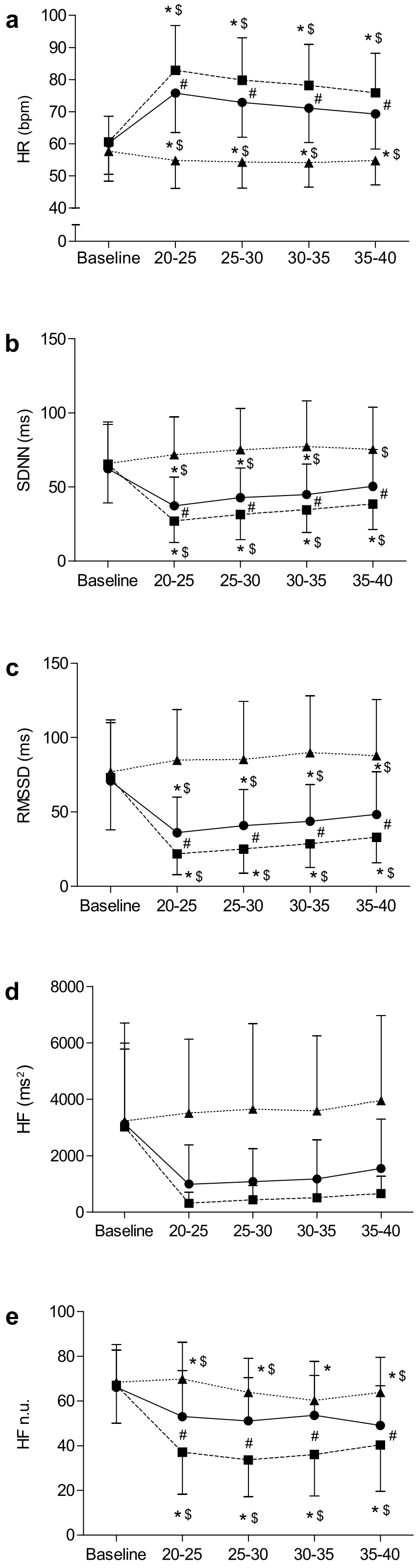
Regarding HFn.u., main effect of session ($p < 0.001$; RTE: 0.364, 0.493, and 0.643 for LSC, SSC, and CON, respectively), time ($p < 0.001$; RTE: 0.673, 0.495, 0.431, 0.441, and 0.460 for Pre, 20–25, 25–30, 30–35, and 35–40, respectively), and a session by time interaction was detected ($p < 0.001$). Post-hoc analyses (Fig. 2e) showed lower values for all post-test epochs in LSC and SSC versus both the baseline and CON in all the epochs ($p < 0.001$–0.031) except the 30–35 min period after SSC. Furthermore, LSC data were consistently lower in comparison with SSC during all the postexercise epochs ($p < 0.001$–0.021). The effect size with respect to baseline values for the cardiac autonomic modulation is reported in Table 2.

For BRS_{count}, a main effect for session ($p < 0.001$; RTE: 0.567, 0.552, and 0.381 for LSC, SSC, and CON, respectively) and a session by time interaction was detected ($p = 0.011$). Nevertheless, a time effect was not observed ($p = 0.212$; RTE: 0.468, 0.529, and 0.503 for baseline, 20–30, and 30–40, respectively). For all periods after training, LSC ($p = 0.042$ and $p = 0.006$ for 20–30 and 30–40 epochs, respectively) and SSC ($p = 0.002$ for both post-test epochs) showed higher values of BRS_{count} in comparison with CON. There were no differences between LSC and SSC at any postexercise time-period (Fig. 3a).

Regarding BRS_{slope}, neither a main effect for session ($p = 0.230$; RTE: 0.461, 0.498, and 0.541 for SSC, LSC, and CON, respectively) or time ($p = 0.387$; RTE: 0.472, 0.533, and 0.495 for Pre, 20–30, and 30–40, respectively) was observed. On the other hand, a significant session by time interaction was detected ($p < 0.001$). In this sense, for all after training periods, lower values for BRS_{slope} were obtained after both LSC ($p < 0.001$in both periods) and SSC ($p < 0.001$ and $p = 0.001$ for 20–30 and 30–40, respectively), in comparison with CON. In this regard, LSC presented lower values at each after training epoch in comparison with SSC ($p < 0.001$ and $p = 0.002$ for 20–30 and 30–40 min, respectively). In addition, both LSC and SSC presented lower values at the period 20–30 in comparison with the baseline ($p < 0.001$ and $p = 0.001$, respectively). However, at the period 30–40 min, the difference with respect to the baseline was still significant in LSC ($p < 0.001$), but not in SSC ($p = 0.053$) (Fig. 3b).

Regarding BEI, only 24 participants were analysed because of missing data. Neither main effect of session ($p = 0.261$; RTE: 0.454, 0.531, and 0.514 for LSC, SSC, and CON, respectively) nor time ($p = 0.254$; RTE: 0.540, 0.487,

Fig. 2 Cardiac autonomic control before (baseline) and after a long ▶ set configuration session (LSC, in squares); a short set configuration session (SSC, in circles), and a control session (CON, in triangles). HR: heart rate (**a**), SDNN: standard deviations of pulse intervals (**b**), RMSSD: root mean square of differences between adjacent pulse intervals (**c**), HF: high-frequency power in absolute values (**d**), HFn.u.: high-frequency power spectral power in normalised units (**e**). *Within-session differences in comparison with baseline, $^{\#}$differences between training sessions at a specific time-period and $^{\$}$differences in comparison with CON at a specific time-period. For clarity, within session comparisons are only shown with respect to the baseline. Data are displayed as means ± SD ($n = 32$)



and 0.473 for baseline, 20–30, and 30–40 min, respectively) was detected. Nevertheless, a significant session by time interaction was observed ($p = 0.029$) such that BEI decreased in LSC after the 20–30 min period time in comparison with baseline ($p = 0.017$), but no significant differences were detected after SSC. However, recovery was only observed during SSC, where there were higher values during the 20–30 min period in comparison with the 30–40 min one ($p = 0.006$) (Fig. 3c). Effect sizes versus the baseline for the cardiac baroreflex response is reported in Table 2.

Regarding LFSBP, our analysis did not detect neither main effect of session ($p = 0.609$; RTE:, 0.512, 0.514 and 0.473 for LSC, SSC, and CON, respectively), time ($p = 0.141$; RTE: 0.461, 0.529, and 0.509 for baseline, 20–30, and 30–40, respectively), nor session by time interaction ($p = 0.104$) (Fig. 3d).

For SBP, DBP, and MAP, no interactions or main effects were observed amongst protocols ($p > 0.05$).

Glycolytic metabolism implication analysis (Δ%Lt) showed higher values of lactatemia ($p < 0.001$; $g = -1.079$; CI −1.598 to − 0.560) after LSC (84.8 ± 6.8%) in comparison with SSC (69.5 ± 18.6%).

Regarding mechanical measurements (Fig. 4), LSC produced a higher loss of velocity in comparison with SSC for all exercises ($p < 0.001$–0.020) as showed by MPV, MMR, and 5LFR analyses.

Discussion

The main findings of this study are that whilst (a) both long and short set configurations produced a reduction of cardiac parasympathetic modulation after a whole-body RT session, (b) the long sets produced a greater drop in comparison with the short sets; (c) there was a higher glycolytic involvement during the long set configuration session concomitant with a prominent loss in mechanical performance versus the short set design. In parallel, there were no alterations regarding the BP or the vascular tone after any session.

Our results indicate that when the intensity of load (15RM), total volume (200 repetitions), and total resting time (360 s between sets for each exercise and 3 min between exercises) are equated, a whole-body RT session including several exercises but differing in the set configuration affects the postexercise cardiac parasympathetic

Table 2 Effect sizes (matched pair rank Biserial correlation, *r*) for heart rate, cardiac autonomic and baroreflex control with respect to the baseline across sessions

	20–25	25–30	30–35	35–40
HR (bpm)				
LSC	1.00	1.00	1.00	0.97
SSC	1.00	1.00	0.98	0.90
CON	− 0.72	− 0.78	− 0.74	− 0.56
SDNN (ms)				
LSC	− 0.99	− 0.95	− 0.94	− 0.96
SSC	− 0.91	− 0.81	− 0.73	− 0.52
CON	0.51	0.57	0.65	0.57
RMSSD (ms)				
LSC	− 1.00	− 0.99	− 0.98	− 0.98
SSC	− 0.93	− 0.89	− 0.80	− 0.76
CON	0.51	0.51	0.61	0.49
HFn.u				
LSC	− 0.98	− 1.00	− 1.00	− 0.98
SSC	− 0.67	− 0.70	− 0.60	− 0.80
CON	0.08	− 0.41	− 0.48	− 0.33

	20–30	30–40
BRScount (*n*)		
LSC	0.19	0.11
SSC	0.45	0.36
CON	− 0.44	− 0.49
$\text{BRS}_{\text{slope}}$ (ms/mmHg)		
LSC	− 0.99	− 0.89
SSC	− 0.71	− 0.48
CON	0.57	0.41
BEI (%)		
LSC	− 0.61	− 0.33
SSC	0.12	− 0.26
CON	− 0.11	− 0.52

Positive values of effect size indicate higher values in comparison with the baseline, whereas a negative effect size indicates decreases in values in comparison with the baseline ($n = 32$ excepted for BEI, $n = 24$)

LSC long set configuration session, *SSC* short set configuration session, *CON* control session, *HR* heart rate, *SDNN* standard deviations of pulse intervals, *RMSSD* root mean square of differences between adjacent PI, *HF* high-frequency PI spectral power in absolute values, *HFn.u.* high-frequency PI spectral power in normalised units, *BRScount* number of baroreceptor sequences detected, *BRSslope* magnitude of the baroreflex sensitivity, *BEI* baroreflex effectiveness index

modulation. In specific, our data demonstrate that the long set configuration produces a significantly greater reduction of cardiac parasympathetic modulation in comparison with the short set configuration during the 40 min postexercise. These results are a novelty since, as far as we know, this is the first study investigating the set configuration effect after a whole-body RT session composed of a series of exercises that match a more traditional style of RT. Previous studies have explored the set configuration effect using a single-exercise model (Iglesias-Soler et al. 2014a; Mayo et al. 2015, 2016), limiting the applicability to typical training protocols routines including several exercises. A previous study by Iglesias-Soler et al. (2014a) showed no differences in cardiac parasympathetic modulation recovery whilst comparing an inter-repetition rest set versus a set to failure during the first postexercise minutes. On the contrary, and in line with our results, Mayo et al. (2015) showed that a long set configuration with a high intensity of effort (8/10, i.e., 80%) and a short set (4/10, 40% intensity of effort) elicited higher reductions of cardiac parasympathetic modulation than a session with a very short set (1/10, i.e.,10%). These findings, along with those of the present study, indicate that the type of set configuration used determines the reductions of the cardiac parasympathetic modulation.

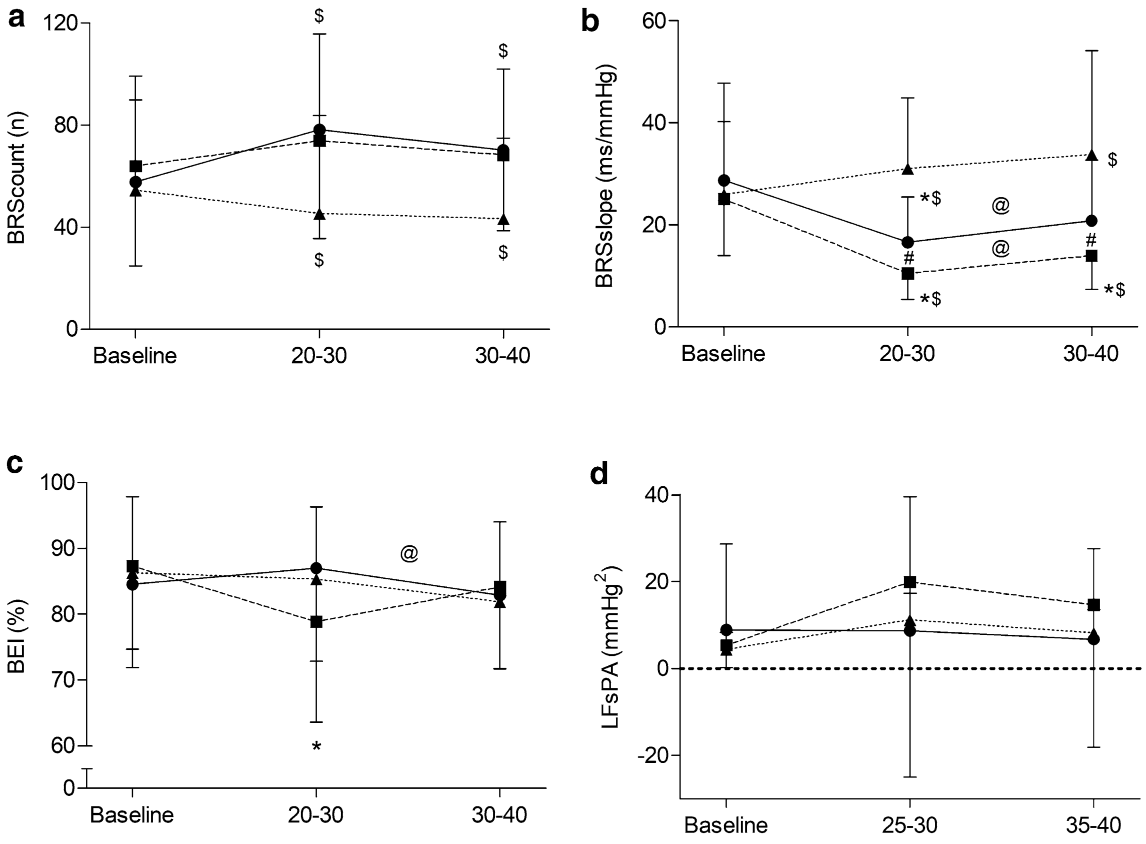


Fig. 3 Cardiac baroreflex control and vascular tone before (baseline) and after a long set configuration session (LSC, in squares), a short set configuration session (SSC, in circles), and a control session (CON, in triangles). **a** BRS$_{count}$: number of baroreceptor sequences detected [ramps simultaneous in systolic blood pressure (SBP) and pulse intervals]; **b** BRS$_{slope}$: magnitude of the baroreflex sensitivity; **c** BEI: Baroreflex effectiveness index; **d** LFSBP: low frequency of SBP. *Within session differences in comparison with baseline, $^{@}$differences between epochs, $^{\#}$differences between training sessions at a specific time-period and $^{\$}$differences in comparison with CON at a specific time-period. Data are displayed as means ± SD ($n = 32$ excepted for BEI, $n = 24$)

Previous investigations have reported that HR is, by itself, a surrogate of autonomic activity (Lahiri et al. 2008) both at rest (Hjalmarson 2007) and during recovery (Jouven et al. 2005). Thus, both are good indexes of increased risk of a cardiac event. In our study, HRV and HR results showed a similar trend. In fact, HR values were higher even after 20 min of the long set configuration, suggesting a slower HR recovery (i.e. a slower parasympathetic reactivation). This reinforces the findings of the effect of set configuration on the autonomic response.

The length of the cardiac parasympathetic modulation reduction lasted up to 40 min after both experimental sessions. Our results partially agreed with Kingsley et al. (2016), who indicated that parasympathetic activity might not be fully recovered up to 30 min after an RT session composed of upper- and lower-body exercises. However, Mayo et al. (2015) reported a shorter time of reduced cardiac parasympathetic modulation for short set configurations. These discrepancies may be due to several reasons. On the one hand, the whole-body multi-exercise nature of our design, that included both single- and multi-joint exercise, in comparison with the one-exercise model employed by Mayo et al. (2015), might partially explain the differences observed. On the other hand, the differences in the intensity of effort magnitude and total volume performed in each study might also determine the recovery of cardiac parasympathetic modulation. Whereas previous studies used less repetitions per session (e.g. the 40 repetitions used by Mayo et al. 2015 or the 90 repetitions by Kingsley et al. 2016), our sessions had each participant complete a total of 200 repetitions. In this sense, a previous study (Figueiredo et al. 2015a) showed that an RT session with a greater volume promotes longer reductions in parasympathetic activity compared to sessions with a lower volume, which is in agreement with our findings..

In addition, even though in our study the time differences only were observed until 40 min postexercise, the magnitude of the reductions suggests that the recovery length in the long set configuration could be longer in comparison with the short structure, but this is speculation. The recovery time

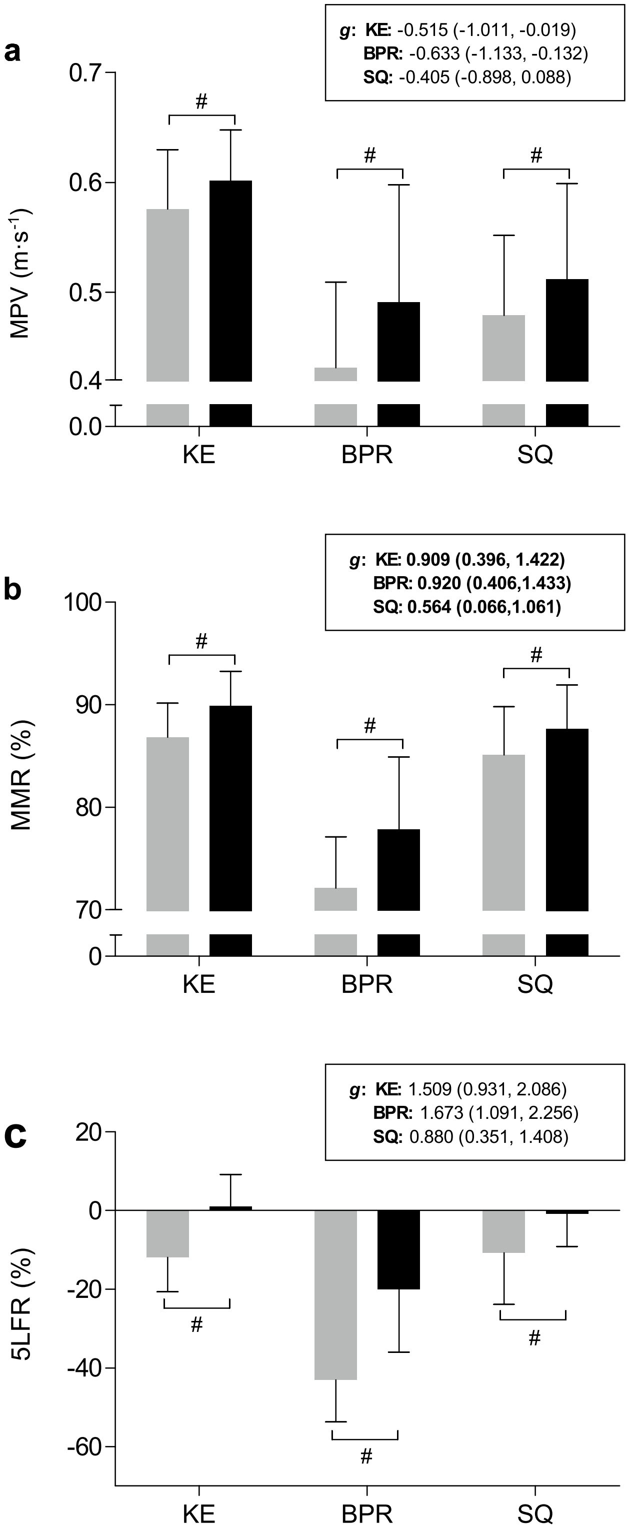


Fig. 4 Mechanical responses during a long set configuration session (LSC, grey bars) and a short set configuration session (SSC, black bars) for the knee extension (KE), bench press (BPR) and parallel squat (SQ) exercises. **a** MPV: average mean propulsive velocity. **b** MMR: mean respect to maximum propulsive velocity ratio. **c** 5LFR: the last five respect to the first five propulsive velocity ratio. $^{\#}$Differences between sessions; *g*: Hedge's *g*. Data displayed as means ± SD (*n* = 32)

differences between protocols may be due to the incapacity of the baroreflex to synchronise the BP responses to changes in HR. Despite that both RT protocols promoted a reduction in BRS during recovery, the long set configuration caused a higher reduction and a slower recovery to the baseline values than the short one, suggesting that this incapacity might be particularly important in more strenuous protocols (Heffernan et al. 2008; Queiroz et al. 2013; Kingsley et al. 2016, 2019). These results are partially in agreement with Mayo et al. (2015). They reported BRS reductions after both long and short intra-set rest configurations but not after the inter-repetition rest training session. Nevertheless, in that particular study, the reductions in comparison with baseline were significant up to 40 min for both set configurations. This may be due to the differences between studies in the intensity of effort used (Mayo et al. 2015). This points out the suitability of managing the set configuration to attenuate the impact on cardiac parasympathetic modulation after RT and to promote a faster recovery whilst maintaining the rest of the loading parameters equated. Thus, shorter sets should be recommended when the aim is to mitigate the effects of RT on cardiac parasympathetic modulation.

The reductions in cardiac baroreflex activity may also be produced by an increase in arterial stiffness triggered by the higher sympathetic tone of central arteries (Heffernan et al. 2007). Our analysis did not detect significant changes in sympathetic vascular tone, which is coincident with Queiroz et al. (2015). In their study, they did not find differences in LFSBP after an RT protocol in healthy men. Conversely, other studies showed increments of LFSBP after RT sessions (Heffernan et al. 2007; Niemelä et al. 2008; Kingsley et al. 2019). Niemelä et al. (2008) compared three different exercise protocols (i.e. aerobic exercise, light resistance exercise, and heavy resistance exercise), and only heavy resistance exercise produced significant increases in LFSBP. These findings suggest that intensity may be a factor affecting the vascular tone, and thus modulating arterial stiffness. Further studies are needed to elucidate the effect of the RT variables on vascular sympathetic tone and how the set configuration might modulate this response in high-intensity protocols.

A possible explanation for the differences in the magnitude of the reduction of the cardiac parasympathetic modulation between sessions may be the different glycolytic involvement of both protocols, since parasympathetic activity is negatively related to lactatemia (Simões et al. 2010; Okuno et al. 2014). Our data demonstrated that the long set configuration produced higher lactate values in comparison with the shorter one. Similar results were observed in previous studies, where sets with a continuous pattern promoted greater lactate response than a work-equated set with an intra-set rest design (Goto et al. 2005; Girman et al. 2014) and a slower recovery to the baseline values (Denton and Cronin 2006).

Regarding the BP analysis, negligible changes were observed after both RT sessions. However, a meta-analysis by Casonatto et al. (2016) demonstrated that a single bout of RT decreases the BP from 60 min up to 24 h after the session. Furthermore, Mayo et al. (2016) only reported BP reductions after session when an RT protocol leading to failure was performed. Therefore, muscular failure may be a key factor in promoting BP reductions and may be a plausible reason why it was not found in our study. Possibly and according to Figueiredo et al. (2015a, b), other loading parameters in our study were not suitable to induce the postexercise hypotension observed in other studies, such as the total volume performed or the intensity selected. On the other hand, it has been suggested that the hypotensive effect is mostly observed in hypertensive people (Kenney and Seals 1993; Queiroz et al. 2015). Thus, the profile of our sample might not be suitable for inducing a hypotensive effect after an acute RT session.

Finally, mechanical measurements' analysis showed a lower velocity loss during the short set configuration exercises performed versus the long set design. These results are coincident with the findings of a recent meta-analysis (Latella et al. 2019), that showed how short set configurations maximise the neuromuscular performance, and in particular, attenuate the loss of velocity during an RT session.

There are some limitations in to the present study that should be considered. First, all women were using oral contraceptive pills and performed the protocols during the mid-follicular to the late luteal phase of their menstrual cycle. In this regard, previous studies suggested that the use of oral contraceptive pills does not affect HRV during the menstrual cycle in healthy women (Teixeira et al. 2015). However, the effects of the menstrual cycle on cardiac autonomic modulation have not been clarified completely (von Holzen et al. 2016). Second, despite the evidence on the validity and reliability of the cardiovascular device used in this study (Fortin et al. 2001), it only provides an indirect assessment of cardiac autonomic modulation. There is extensive debate regarding the relationship between changes in cardiac variability and the activity of a particular branch of the autonomic nervous system (Parati et al. 2006). To improve the physiological interpretation of autonomic data, the study design was developed controlling the possible confounding variables such as respiratory rate, steady-state, participant, or environmental conditions. In this sense, we controlled breathing frequency to avoid the effect of the increased respiratory rate after exercise on HRV measures (Penttila et al. 2001). This is because the respiratory activity is involved in the change in power spectral density distribution, particularly the measures of parasympathetic modulation (HF and HFn.u.) (Brown et al. 1993; Weippert et al. 2015). Whilst breath control might have removed some experimental effects (Berntson et al. 1997), the changes are presumed to be similar between protocols based on data that paced breathing and spontaneous breathing may result in similar effects (Wang et al. 2013); however, more research on this topic is pertinent. Furthermore, due to the technical limitations regarding the time spent to apply the instrumentation and calibrate the device, from the end of the session to 20 min, HR and BP were not evaluated. Further investigations with measurements during and immediately after the exercise must be carried out to assess the effect of set configuration on HR kinetics. Last, our participants were healthy and active young adults and performed two protocols with specific load characteristics, limiting the extrapolation of our results to other protocols or other population profiles. Further studies are needed to explore the acute and chronic effects of different set configurations on the cardiac autonomic modulation and cardiac baroreflex in populations at cardiovascular risk.

Conclusions

In summary, our findings suggest that a moderate-intensity high-volume RT session using a long set configuration during several exercises produces a higher cardiac parasympathetic withdrawal in comparison with a short set configuration design. Based on these findings, a short set configuration should be prescribed to design safer RT sessions with lower reductions of cardiac parasympathetic modulation whilst the mechanical performance of the session is optimised.

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Author contributions EIS, MR, and XM conceived and designed research. MRA and EIS conducted experiments. MRA and EIS analysed data. MRA, EIS, XM, JM, and JDK drafted and critically revised the manuscript.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional research committee and with the 1964 Helsinki Declaration and its later amendments or comparable standards.

Informed consent Written informed consent was obtained from all individual participants included in the study.

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