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Baroreflex and autonomic responses to two equated isometric resistance exercise protocols in females

Resposta barorreflexa e autonômica em dois protocolos de exercício isométrico equalizados em mulheres

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Abstract – Different resistance exercise set configurations seem to lead to distinct hemodynamic, baroreflex and autonomic responses. Nevertheless, both the baroreflex and the autonomic reactivity to an equated work-to-rest ratio (W:R-equated) isometric exercise (IE) session in females still must be clarified. Thus, the present work investigated the autonomic and baroreflex responses of two W:R-equated isometric exercise sessions in female participants. Nine healthy females (25 ± 3 years) performed two isometric protocols equated by W:R with 30% 1-RM - a long set configuration (LSC): 4 sets x 2 min isometric x 2 min rest; and a short set configuration (SSC): 16 sets x 30 s isometric x 24s rest. Blood pressure (BP) and cardiac intervals were monitored by photoplesthysmography and electrocardiogram before, during and after (immediately, 30 and 60 min) exercise. The time domain parameters and frequency domain measures of the heart rate variability were calculated along with the baroreflex gain and effectiveness. A two-way repeated measures ANOVA was applied. Both protocols evoked a reduction in the baroreflex gain, whereas the LSC gain reduction lasted longer (30 and 60 minutes). Only the SSC was able to lower the root mean square of successive differences between normal heart beats (RMSSD) during exercise, when compared to pre-session values ($p < 0.05$). The standard deviation of the normal-to-normal interval (SDNN) increased during exercise with the LSC protocol ($p<0.05$). The high-frequency (HF) band only decreased during exercise using the SSC protocol ($p < 0.05$), while the LF/HF ratio was also only elevated in the SSC during exercise ($p<0.05$). The LSC evoked more prolonged reductions in the baroreflex gain, while the SSC protocol caused a greater disturbance in cardiac autonomic modulation.

Key words: Parasympathetic nervous system; Baroreflex; Isometric exercise; Set configuration.

Resumo – *Diferentes configurações de prescrição de séries podem provocar diferentes respostas hemodinâmicas, barorreflexas e autonômicas. No entanto, a reatividade barorreflexa e autonômica a uma sessão de exercício isométrico (EI) equalizado pela razão impulso-repouso (I:R) em mulheres ainda precisa ser esclarecida. Assim, a presente pesquisa investigou as respostas autonômicas e barorreflexas em mulheres, utilizando dois protocolos de EI. Nove mulheres saudáveis (25 ± 3 anos) realizaram dois protocolos equalizados em I:R com 30% 1-RM: configuração de série longa (LSC – long set configuration): 4 séries x 2min isométricos x 2min de descanso; e configuração de série curta (SSC – short set configuration): 16 séries x 30seg isométricos x 24seg de descanso. A pressão arterial e os intervalos cardíacos foram monitorizados por fotopletismografia e eletrocardiograma antes, durante e após (imediatamente, 30 e 60 min) o exercício. Foram calculados os parâmetros no domínio do tempo e frequência da variabilidade relativa à frequência cardíaca, assim como o ganho e eficácia do barorreflexo. Foi aplicada uma ANOVA de duas vias para medidas repetidas. Os protocolos provocaram uma redução no ganho do barorreflexo, enquanto a redução de ganho da LSC durou mais tempo (30 e 60 minutos). Apenas a SSC foi capaz de diminuir a raiz quadrada da média do quadrado das diferenças entre os intervalos RR normais adjacentes (RMSSD – root mean square of successive differences between normal heartbeats) durante o exercício em comparação com o repouso ($p < 0,05$). O desvio padrão de todos os intervalos RR normais (SDNN – standard deviation of the normal-to-normal interval) aumentou durante o exercício utilizando a LSC ($p<0,05$). A HF diminuiu apenas no SSC durante o exercício ($p < 0,05$), enquanto a relação LF/HF também aumentou apenas no SSC durante o exercício ($p < 0,05$). A LSC provocou reduções mais prolongadas no ganho do barorreflexo, enquanto o protocolo SSC causou uma maior perturbação na modulação autonômica cardíaca.*

Palavras-chave: *Sistema nervoso parassimpático; Barorreflexo; Exercício isométrico; Configuração de séries.*

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INTRODUCTION

Isometric contractions keep the muscle in an equal length and maintain the same joint angle throughout muscle actions, resulting in high intramuscular pressure[1]. Compared to a dynamic exercise of the same relative intensity[1–3], the isometric resistance exercise (IE) promotes a greater sympathetic autonomic modulation and higher scores of perceived exertions[4].

Mechanoreceptors located in the carotid sinus bifurcation and the aortic arch monitor blood pressure (BP) using a beat-by-beat assessment[5]. These structures continuously transmit neuronal signals to the brainstem, promptly mitigating sudden BP disturbances by modulating the heart rate (HR), stroke volume and total vascular conductance through an autonomic regulation[5,6]. This reflex adjustment of cardiac intervals (R-R) in response to BP alterations can be inferred as a baroreflex gain, which can be derived by analyzing the pulse intervals and the systolic BP values through the sequence method, hence reflecting the baroreflex sensitivity (BRS)[7,8]. Although the baroreflex reduces sudden high BP at rest, during exercise, it is reset to operate at higher BP levels, allowing BP increases to supply oxygen and nutrients to the active skeletal muscles[9,10]. Baroreflex resets in an intensity-dependent manner[11] in response to dynamic[12,13] and IE[14].

Conflicting findings have been reported regarding the baroreflex response to IE. González-Camarena et al.[3] observed no changes in baroreflex gain during a 6-min 30% maximum voluntary contraction (MVC) knee extension in males. In contrast, Teixeira et al.[15] found an increased baroreflex gain after two 2-minute sets of isometric handgrip exercise for each limb (30% MVC) in both males and females. More recently, Samora et al.[16] also reported increased baroreflex sensitivity gain after 90 s of isometric handgrip with 40% MVC followed by 3-min post-exercise ischemia in males, but not females. This effect was observed during post-exercise ischemia and 5-min after it.

Even though load intensity is a determinant factor for the magnitude of the baroreflex response[11], different set configurations may also lead to distinct baroreflex responses[17,18]. Indeed, Mayo et al.[17] applied three distinct dynamic resistance exercise sessions (5 x 8:180 s; 10 x 4:80 s; 40 x 1:18.5 s) with the same total time under tension and total resting time, using 10-RM load (equated intensity, volume and work-to-rest ratio [W:R]). Both protocols performed with more than one repetition per set presented lower gain than resting values, but only 5 x 8:180 s showed lower gain than 40 x 1:18.5 s.

Using the IE, Río-Rodríguez, Iglesias-Soler and Olmo[17] conducted two knee extension sessions with the same total W:R with 50% MVC. One session consisted of 4 sets, each one lasting 80% of the time to task failure in the 50% MVC maximal test and with 180 seconds rest between sets. The other session consisted of 16 sets, each one lasting 20% of the time to task failure in 50% MVC maximal test, with 36s rest between sets. Baroreflex sensitivity gain was impaired immediately after the session using the longer sets protocol, when compared to the shorter sets protocol. However, the IE applying large muscle mass and the effects of its configuration on the baroreflex activity remains to be fully understood. Investigations regarding only female participants are still scarce, yet it is essential to better comprehend baroreflex activity during and after exercise. It is evident that there are differences in the baroreflex gain and autonomic modulation at rest between males and females[15,19]. Furthermore, studies assessing baroreflex gain in longer periods after IE with distinct set configurations are also lacking. Therefore, the present study aimed to investigate both the baroreflex and autonomic function measured continuously before, during and after two W:R isometric resistance exercise sessions equated in intensity and total volume.

METHODS

Subjects

Nine normotensive and physically active females participated in this study (age: 25 ± 3 years; height: 1.64 ± 0.07 m; weight: 60.1 ± 5.7 Kg; body mass index [BMI]: 22.1 ± 1.2 Kg/m^2; resting systolic blood pressure [SBP]: 112 ± 9 mmHg; resting diastolic blood pressure [DBP]: 71 ± 5 mmHg; resting heart rate [HR]: 72 ± 10 bpm; 1 maximal repetition [1-RM] using the Leg Press machine: 256 ± 57 kg; 30% 1-RM using the Leg Press machine: 77 ± 17 kg). Participants were asked to refrain from any exercise during the experimental period. The sample was composed of females between 18 and 30 years old, physically active, normotensive and without chronic diseases or previous injuries. Individuals that proved to be unable to finish any protocol or presented 260 or 120 mmHg for SBP and DBP during the effort, respectively, were excluded from the present study. All procedures were executed according to the Brazilian National Health Council, and the study was approved by the Human Research Ethics Committee of the Federal University of Espírito Santo (No. 90076218.0.0000.5542/2018).

Experimental design

On their first visit to the laboratory, participants were familiarized with the Leg Press machine (SICKERT, Vila Velha, Brazil) to be used in the protocols, performing one set of ten repetitions, followed by two IE sets of 30 seconds each with no additional weight in both dynamic and static sets. One day later, a 1-RM test was conducted to assess maximal strength and determine the load adopted in both protocols. A retest was performed 48 hours later. After five days, the first protocol was applied, followed by a one week interval until the next protocol. Each participant performed both protocols in random order.

Maximal strength test (1-RM)

It was applied a test to determine the maximal load required to perform one repetition in the Leg Press machine, following the 1-RM testing guidelines[20]. In preparation, two warm-up sets were carried out, the first with ten repetitions and the second with five repetitions, separated by a 1-minute rest interval. Warm-up loads were set at 50% and 70% of self-reported 1-RM load, respectively. The test was initiated two minutes after warm-up, consisting of up to five attempts to lift the determined load, with a 5-minute interval between trials. The greatest load lifted with the correct technique was set as 1-RM load. A retest was performed to verify the intraclass correlation coefficient (ICC) and confirm the 1-RM load. The highest load lifted was used to establish the protocol's load.

Isometric resistance exercise sessions

Two experimental sessions equated in total volume and intensity, but different set configurations were executed. One session with a long set configuration (LSC) consisted of four isometric sets of 2-min separated by 2 min of rest (4 x 2 min:2 min). In contrast, the other session with a short set configuration (SSC) consisted of 16 isometric sets of 30 s separated by 24 s intervals (16 x 30 s:24 s). Both protocols were employed with 30% 1-RM, and isometric contractions were performed with 90° knee flexion. Participants were instructed to avoid Valsalva's maneuver the whole time.

Blood pressure and cardiac interval data assessment

Pulsatile BP was measured with non-invasive infra-red photoplesthysmography (Finometer®, Finapres Medical System, Netherlands). R-R intervals were acquired using electrocardiogram (Finometer®, Finapres Medical System, Netherlands). Both signals were recorded using the BeatScope® software. Initially, participants were positioned on Leg Press and equipped with brachial and middle finger cuffs attached to their left upper limb. Electrodes were applied according to the manual user's guide. BP was continuously assessed 10 minutes pre-exercise, during protocol execution (14 min of duration each), and post-exercise (immediately, 30 and 60 min after the session).

Baroreflex sensitivity

Baroreflex sensitivity gain was evaluated using the sequence technique[21]. This approach identifies three or more consecutive beats in which the progressive increases or decreases in SBP are followed by the progressive lengthening or shortening of R-R intervals, respectively. Baroreflex sequences were detected by computer software (CardioSeries v2.7, Brazil). BRS gain was determined for upward (Up Gain), downward (Down Gain), and all combined sequences (All Gain).

The baroreflex effectiveness index (BEI) was calculated by the ratio between the number of upward (Up BEI) and downward (Down BEI) sequences, along with the total number of SBP ramp-like changes[21,22].

Heart rate variability

The R-R interval time series were used to assess both frequency and time domain heart rate variability (HRV) parameters through the CardioSeries v2.7 software. The pre-session data collection was performed for 10 minutes, the first minute to ensure signal stabilization and the two last minutes to avoid the influence of the anticipatory effect of exercise, being excluded from the present analysis. The post-exercise period was assessed immediately, 30 and 60 minutes after the session.

This study included time domain parameters such as the standard deviation of the normal-to-normal interval (SDNN), the root mean square of successive differences between normal heartbeats (RMSSD), and the mean R-R interval values. The SDNN indicates global HRV function, while the RMSSD reflects mainly the parasympathetic modulation[23].

Frequency domain measures consisted of low-frequency (LF) and high-frequency (HF) bands, representing mostly sympathetic and parasympathetic modulation. The ratio between these bands (LF/HF), which infers the sympathovagal balance[23], was also assessed.

Systolic blood pressure variability

SBP variability was evaluated using the CardioSeries® v2.7 through an SBP time series to investigate the central sympathetic modulation of the vascular system[24]. Values were expressed by means of the SBP along with the LF ($mmHg^2$) and the HF band of the SBP spectral analysis.

Statistical analysis

The normal distribution of all data was confirmed through the Shapiro-Wilk test. The ICC coefficient was calculated to assess the 1-RM test reproducibility. A two-way ANOVA was applied for repeated measures (time x protocol), followed by the Bonferroni Post-hoc test. In order to perform the analysis (Baroreflex and HRV), data were divided into before, during, and after (immediate, 30-minute, and 60-minute) exercise sessions. All statistical analyses were conducted using the SPSS® v20.0 software (SPSS, Inc., Chicago). The significance level adopted was $p < 0.05$.

RESULTS

Baroreflex gain

The two-way ANOVA only detected the time effect for repeated measures: Up Gain ($F = 23.493$; $p < 0.05$), Down Gain ($F = 39.232$; $p < 0.05$), and All Gain ($F = 32.802$; $p < 0.05$). No effect was found for the protocol: (Up Gain [$F = 1.177$; $p > 0.05$], Down Gain [$F = 0.605$; $p > 0.05$] and All Gain [$F = 0.968$; $p > 0.05$]) neither for the interaction between time and protocol (Up Gain [$F = 0.306$; $p > 0.05$], Down Gain [$F = 0.292$; $p > 0.05$] and All Gain [$F = 0.305$; $p > 0.05$]).

In response to the LSC protocol, the Up Gain decreased until 30 minutes after the exercise ($p < 0.05$). All Gain and Down Gain also reduced, remaining lower than the pre-values up to 60 minutes after the exercise ($p < 0.05$) (Table 1).

After the SSC protocol, Up Gain and All Gain only lowered during exercise ($p < 0.05$). Furthermore, the Down Gain showed a decrease up to 30 minutes after exercise ($p < 0.05$) (Table 1).

Baroreflex effectiveness index

The ANOVA detected a time effect for all indexes, namely: Up BEI ($F = 43.136$; $p < 0.05$), Down BEI ($F = 11.863$; $p < 0.05$) and All BEI ($F = 33.914$; $p < 0.05$). No effect for was found for the following protocols: Up BEI ($F = 0.002$; $p > 0.05$), Down BEI ($F = 0.029$; $p > 0.05$), and All BEI ($F = 0.004$; $p > 0.05$), where only the Up BEI presented interaction between time and protocol ($F = 3.598$; $p < 0.05$).

Decreases in the Up BEI and All BEI were observed during exercise ($p < 0.05$) as well as at the end of exercise ($p < 0.05$), when compared to pre-values in both protocols. Only the LSC protocol presented a difference in Down BEI, which lowered during exercise ($p < 0.05$), with no differences in the comparison between pre- and post-exercise session ($p > 0.05$) (Table 2).

Systolic blood pressure variability

The ANOVA showed the time effect for the BP ($F = 65.028$; $p < 0.05$) and the LF ($F = 23.125$; $p < 0.05$). No effect was detected for the protocol (BP: $F = 1.090$; $p > 0.05$; LF: $F = 2.922$; $p > 0.05$) nor for the interaction between time and protocol (BP: $F = 2.012$; $p > 0.05$; LF: $F = 0.831$; $p > 0.05$).

In both protocols, BP and LF were elevated only during exercise ($p < 0.05$), while no differences found in the comparison between pre- and post-exercise ($p > 0.05$) (Table 3).

Heart rate variability

Time domain

The ANOVA presented a time effect (R-R: $F = 89.591$; $p < 0.05$; SDNN: $F = 7.015$; $p < 0.05$; RMSSD: $F = 7.772$; $p < 0.05$), but no effect for the protocol was found (RR: $F = 0.068$; $p > 0.05$; SDNN: $F = 2.290$; $p > 0.05$; RMSSD: $F = 1.960$; $p > 0.05$). Interaction between time and protocol was detected for the SDNN ($F = 5.414$; $p < 0.05$) and the RMSSD ($F = 3.485$; $p < 0.05$).

In response to the LSC protocol, R-R intervals were reduced until 60 minutes after exercise ($p < 0.05$). SDNN values augmented only during exercise ($p < 0.05$). No differences were found for the RMSSD ($p > 0.05$) (Table 4).

For the SSC protocol, R-R intervals decreased immediately after exercise ($p < 0.05$). The SDNN showed no differences at any moment ($p > 0.05$), while the RMSSD was reduced during exercise ($p < 0.05$) (Table 4).

Bonferroni's *post-hoc* analysis indicated differences between protocols during exercise in the SDNN, which was higher during the LSC protocol ($p < 0.05$), and in the RMSSD, which was lower during the SSC protocol ($p < 0.05$).

Frequency domain

The ANOVA presented a time effect (LF: $F = 5.096$; $p < 0.05$; HF: $F = 4.906$; $p < 0.05$; LF/HF: $F = 7.851$; $p < 0.05$), but no effect for the protocol (LF: $F = 0.077$; $p > 0.05$; HF: $F = 1.576$; $p > 0.05$; LF/HF: $F = 0.112$; $p > 0.05$), neither for the interaction between time and protocol (LF: $F = 0.510$; $p > 0.05$; HF: $F = 1.048$; $p > 0.05$; LF/HF: $F = 1.481$; $p > 0.05$).

No differences were found in the LSC protocol in any index ($p > 0.05$). In response to the SSC protocol, HF values decreased immediately after exercise ($p < 0.05$), while the LF/HF ratio rose during exercise in comparison with the pre-exercise session values ($p < 0.05$). No differences were observed in LF values at any moment ($p > 0.05$) (Table 5).

Table 1. Baroreflex gain among protocols.

BAROREFLEX SENSITIVITY (BRS) (ms/mmHg²)					
LSC					
Gain	Pre	During	After	Post 30 min	Post 60 min
Up Gain	16.08±5.12	8.06±4.57*	8.74±4.64*	11.75±5.68*	13.65±6.00
Down Gain	15.81±4.45	6.86±3.20*	7.88±3.78*	10.69±3.81*	12.56±4.08*
All Gain	15.94±4.74	7.41±3.80*	8.34±4.22*	11.23±4.69*	13.08±4.83*
SSC					
Gain	Pre	During	After	Post 30 min	Post 60 min
Up Gain	15.70±6.37	6.45±2.56*	8.13±4.08	10.44±2.53	11.91±2.79
Down Gain	16.06±5.47	5.69±2.04*	7.50±3.59*	10.27±2.82*	11.49±2.08
All Gain	15.85±5.92	6.02±2.16*	7.87±3.89	10.28±2.43	11.73±2.19

Note: Up Gain: sequence of three consecutive beats characterized by both BP increase and R-R interval lengthening; Down Gain: sequence of three consecutive beats characterized by both BP decrease and R-R interval shortening; All Gain: combination of Up and Down sequences; *p < 0.05 vs Pre.

Table 2. Baroreflex effectiveness index among protocols.

BAROREFLEX EFFECTIVENESS INDEX (BEI)					
LSC					
BEI	Pre	During	After	Post 30 min	Post 60 min
Up BEI	0.71±0.06	0.32±0.11*	0.49±0.15*	0.67±0.11	0.68±0.14
Down BEI	0.61±0.09	0.39±0.15*	0.46±0.11	0.59±0.13	0.57±0.18
All BEI	0.65±0.06	0.35±0.12*	0.48±0.12*	0.63±0.10	0.62±0.12
SSC					
BEI	Pre	During	After	Post 30 min	Post 60 min
Up BEI	0.73±0.06	0.36±0.13*	0.56±0.10*	0.62±0.07	0.60±0.06
Down BEI	0.60±0.10	0.44±0.10	0.45±0.09	0.54±0.08	0.55±0.08
All BEI	0.66±0.06	0.40±0.11*	0.51±0.09	0.57±0.05	0.58±0.05

Note: Up BEI: the ratio between the total number of BP rises and the number of times the R-R interval was lengthened following BP increase; Down BEI: the ratio between the total number of BP decreases and the number of times R-R interval was shortened following BP reduction; All BEI: ratio between total number of BP rises and decreases followed by lengthening and shortening of R-R intervals, respectively; *p < 0.05 vs Pre.

Table 3. Systolic blood pressure variability among protocols.

SYSTOLIC BLOOD PRESSURE VARIABILITY					
LSC					
Index	Pre	During	After	Post 30 min	Post 60 min
Mean BP (mmHg)	119.5±11.1	151.6±12.33*	117.8±12.26	119.1±9.48	123.2±10.9
LF (mmHg2)	4.67±2.68	21.97±14.18*	8.48±5.11	8.23±4.89	6.76±3.44
SSC					
Index	Pre	During	After	Post 30 min	Post 60 min
Mean BP (mmHg)	121.4±7.8	150.3±15.17*	118.0±9.66	124.6±9.2	129.9±10.1
LF (mmHg2)	5.89±3.07	29.08±14.04*	9.07±3.44	8.93±3.92	8.60±4.45

Note: Mean BP (mmHg): mean values of systolic arterial pressure; LF (mmHg²): low-frequency band of BP spectral analysis; *p < 0.05 vs. Pre.

Table 4. Heart rate variability among protocols (time domain).

HEART RATE VARIABILITY (TIME DOMAIN)					
LSC					
Time Domain	Pre	During	After	Post 30 min	Post 60 min
R-R (ms)	807.8±80.3	520.3±62.7*	637.1±76.6*	718.9±63.4*	746.8±73.7*
SDNN (ms)	60.0±16.2	88.6±20.1*†	82.3±22.0	64.5±20.2	63.7±17.0
RMSSD	44.1±16.4	39.4±19.3	26.9±9.9	35.9±13.4	42.4±17.1
SSC					
Time Domain	Pre	During	After	Post 30 min	Post 60 min
R-R (ms)	782.7±79.6	534.5±89.9*	660.1±103.2*	725.8±78.7	752.9±76.1
SDNN (ms)	62.9±12.8	60.8±5.0	72.0±11.4	58.7±14.1	66.3±14.6
RMSSD	42.3±11.4	20.7±7.6*†	25.8±12.6	36.1±12.3	40.8±12.5

Note: R-R (ms): R-R intervals; SDNN: standard deviation of the normal-to-normal R-R intervals; RMSSD: Root mean square of successive differences between normal heartbeats; *p < 0.05 vs Pre; †p < 0.05 between protocols.

Table 5. Heart rate variability among protocols (frequency domain).

HEART RATE VARIABILITY (FREQUENCY DOMAIN)					
LSC					
Frequency domain	**Pre**	**During**	**After**	**Post 30 min**	**Post 60 min**
LF (ms2)	702.6±344.1	486.0±322.0	371.1±287.1	976.6±945.3	1058.9±1123.6
HF (ms2)	969.7±831.6	633.8±493.3	280.4±224.7	592.8±543.5	888.3±914.2
LF/HF	1.13±0.58	2.38±1.31	3.09±2.18	2.83±1.54	1.96±0.82
SSC					
Frequency domain	**Pre**	**During**	**After**	**Post 30 min**	**Post 60 min**
LF (ms2)	692.7±252.0	395.8±257.5	466.2±337.3	822.4±384.6	1030.2±635.7
HF (ms2)	789.8±352.5	231.7±170.4*†	299.9±270.6*	531.5±283.5	675.5±408.3
LF/HF	1.34±0.98	3.40±1.84*	2.69±1.61	2.18±0.92	2.20±0.97

Note: LF (ms^2): low-frequency band; HF (ms^2): high-frequency band; LF/HF: the ratio between low and high-frequency bands; *p < 0.05 vs. Pre; †p < 0.05 between protocols.

DISCUSSION

The present study investigated the effects of two isometric resistance exercise protocols on the baroreflex and autonomic function, which were continuously assessed before, during, and after exercise sessions. The main findings herein were: (1) the LSC protocol induced a greater impact in the baroreflex response, reducing the BRS gain for a longer period than the SSC protocol; (2) the SSC protocol led to a greater parasympathetic withdrawal during exercise, characterized by the higher reduction in the HF and the RMSSD.

The distinct baroreflex responses between protocols could be partially explained by the longer time under tension during the LSC protocol. Specifically, the prolonged duration of muscular contraction for extended periods may lead to local metabolite accumulation, such as lactate, inorganic phosphate and reactive oxygen species[25], increasing exercise-induced metaboreflex.

Previous studies using IE found distinct alterations in BRS gain after sessions[26–28]. Iellamo et al.[26] did not observe changes in the BRS gain after 2 min of 30% MVC handgrip exercise in normotensive males. Likewise, Fisher et al.[27] found no differences in BRS gain after 2 min of 35% and 45% MVC, followed by 3 min post-exercise ischemia. In a slightly different approach, Hartwich et al.[28] applied rhythmic 1 s handgrip contractions separated by 2 s each in normotensive males for 17.5 min, resulting in 20 contractions per minute. No baroreflex gain alterations were observed. This approach is comparable to the SSC protocol used in the present study, since both established more pauses between muscle actions. Indeed, the data herein corroborates previous studies, given that the SSC protocol had a smaller impact on the baroreflex gain than the LSC protocol.

In this sense, Mayo et al.[17] investigated the baroreflex response to distinct set configurations using the same load and with W:R-equated. Despite finding the same total time under tension and resting time (5 x 8:180 s; 10 x 4:80 s; 40 x 1:18.5 s), the BRS gain was differently affected. The protocol with longer sets (5 x 8:180 s) caused a greater BRS gain impairment, which is similar to the present study findings.

Regarding the HRV in the time domain, the LSC protocol exhibited a greater increase in SDNN (after). It decreased the R-R intervals (during, after, 30 and 60 minutes) for longer than the SSC protocol. However, only the SSC protocol led to a reduction in RMSSD during exercise. The differing resting times between protocols may partially explain these discrepancies. The longer interval between sets in the LSC allowed for a greater parasympathetic recovery, when compared to the SSC protocol.

The increase in the SDNN during the LSC protocol is consistent with previous studies investigating the HRV during IE, presenting higher values than a cycling protocol with the same duration and HR response[2]. In the present study, higher SDNN values during the LSC protocol could be attributed to the longer sets and intervals. This would enhance the metaboreflex and sympathetic firing[1], increasing the HR and shortening R-R intervals during effort. During rest periods, the longer intervals would contribute to a greater vagal recovery than the SSC, reducing the HR and increasing R-R intervals. Consequently, the SDNN during the protocol would be higher.

Río-Rodríguez et al.[18] compared two distinct IE protocols using knee extension at 50% MVC in the frequency domain. One exercise session was conducted with four sets lasting 80% of the time to task failure, separated by three minutes. The other session consisted of 16 sets lasting 20% of the time to task failure with 36 s intervals between sets. The authors reported a more significant reduction in HF after protocol with longer sets and intervals, as well as a LF increase after the short sets and intervals protocol. These HF results are contrary to the findings of this work, since it was not observed any differences between protocols after the session, only during exercise. A more pronounced HF reduction in the SSC protocol was observed during exercise, with a slight recovery at the immediate end of the session. In the LSC protocol, a progressive HF reduction was registered until the immediate end of the session, at which point values were similar for both protocols.

Río-Rodríguez et al.[18] reported higher LF in response to shorter sets and intervals, which is consistent with the present study results, given that the SSC protocol demonstrated a higher LF/HF. Although these indices are not identical, increases in both parameters can suggest a higher sympathetic modulation. Similarly to the findings herein, the authors also reported a greater reduction in BRS gain while using the protocol with a longer time under tension[18].

CONCLUSIONS

The LSC protocol induced longer reductions in baroreflex gain, while the SSC protocol led to a greater disturbance in cardiac autonomic modulation. These results suggest that different isometric set configurations equated in W:R may lead to distinct baroreflex and autonomic responses. Despite further investigation still being needed, inserting more resting periods between sets could be a strategy for causing less disturbance in the BRS, which might interest clinical populations.

COMPLIANCE WITH ETHICAL STANDARDS

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Ethical approval

Ethical approval was obtained from the local Human Research Ethics Committee – Federal University of Espírito Santo and the protocol (nº. 90076218.0.0000.5542/2018) was written in accordance with the standards set by the Declaration of Helsinki.

Conflict of interest statement

The authors have no conflict of interest to declare.

Author Contributions

Conceived and designed the experiments: RDL and CBFR. Performed the experiments: CBFR, IAM, VHGN, LRAM, and LNSN. Analyzed the data: IAM, GFFS, RDL. Wrote the manuscript: IAM. Finalized and critically revised: LC, GFFS, RDL.

REFERENCES

1. Fisher JP, Young CN, Fadel PJ. Autonomic adjustments to exercise in humans. Compr Physiol. 2015;592:475-512.
2. Weippert M, Behrens K, Rieger A, Stoll R, Kreuzfeld S. Heart rate variability and blood pressure during dynamic and static exercise at similar heart rate levels. PLoS One. 2013;8(12):e83690. http://doi.org/10.1371/journal.pone.0083690. PMid:24349546.
3. Gonzalez-Camarena R, Carrasco-Sosa S, Roman-Ramos R, Gaitán-González MJ, Medina-Bañuelos V, Azpiroz-Leehan J. Effect of static and dynamic exercise on heart rate and blood pressure variabilities. Med Sci Sports Exerc. 2000;32(10):1719-28. http://doi.org/10.1097/00005768-200010000-00010. PMid:11039644.
4. Swift HT, O'Driscoll JM, Coleman DD, de Caux A, Wiles JD. Acute cardiac autonomic and haemodynamic responses to leg and arm isometric exercise. Eur J Appl Physiol. 2022;122(4):975-85. http://doi.org/10.1007/s00421-022-04894-7. PMid:35089384.
5. la Rovere MT, Pinna GD, Raczak G. Baroreflex sensitivity: measurement and clinical implications. Ann Noninvasive Electrocardiol. 2008;13(2):191-207. http://doi.org/10.1111/j.1542-474X.2008.00219.x. PMid:18426445.
6. Fadel PJ. Reflex control of the circulation during exercise. Scand J Med Sci Sports. 2015;25(Suppl 4):74-82. http://doi.org/10.1111/sms.12600. PMid:26589120.
7. Rovere M, Mortara A, Schwartz P. Baroreflex sensitivity. J Cardiovasc Electrophysiol. 1995;6(9):761-74. http://doi.org/10.1111/j.1540-8167.1995.tb00452.x. PMid:8556196.
8. Reyes del Paso GA, Hernández JA, González MI. Differential evaluation of the baroreceptor cardiac reflex effectiveness as a function of sequence length. Int J Psychophysiol. 2006;59(2):91-6. http://doi.org/10.1016/j.ijpsycho.2005.02.006. PMid:15925420.
9. Ogoh S, Fisher JP, Dawson EA, White MJ, Secher NH, Raven PB. Autonomic nervous system influence on arterial baroreflex control of heart rate during exercise in humans. J Physiol. 2005;566(Pt 2):599-611. http://doi.org/10.1113/jphysiol.2005.084541. PMid:15890708.

10. Fadel P. Arterial baroreflex control of the peripheral vasculature in humans. Med Sci Sports Exerc. 2008;40(12):2055-62. http://doi.org/10.1249/MSS.0b013e318180bc80. PMid:18981944.

11. Raven PB, Fadel PJ, Ogoh S. Arterial baroreflex resetting during exercise: a current perspective. Exp Physiol. 2006;91(1):37-49. http://doi.org/10.1113/expphysiol.2005.032250. PMid:16210446.

12. Kingsley JD, Tai Y-L, Marshall EM, Glasgow A, Oliveira R, Parks JC, et al. Autonomic modulation and baroreflex sensitivity after acute resistance exercise: responses between sexes. J Sports Med Phys Fitness. 2019;59(6):1036-44. http://doi.org/10.23736/S0022-4707.18.08864-3. PMid:30035471.

13. Heffernan K, Collier S, Kelly E, Jae S, Fernhall B. Arterial stiffness and baroreflex sensitivity following bouts of aerobic and resistance exercise. Int J Sports Med. 2007;28(3):197-203. http://doi.org/10.1055/s-2006-924290. PMid:17024636.

14. Fisher JP, Ogoh S, Young CN, Keller DM, Fadel PJ. Exercise intensity influences cardiac baroreflex function at the onset of isometric exercise in humans. J Appl Physiol. 2007;103(3):941-7. http://doi.org/10.1152/japplphysiol.00412.2007. PMid:17585044.

15. Teixeira AL, Ritti-Dias R, Antonino D, Bottaro M, Millar PJ, Vianna LC. Sex differences in cardiac baroreflex sensitivity following isometric handgrip exercise. Med Sci Sports Exerc. 2018;50(4):770-7. http://doi.org/10.1249/MSS.0000000000001487. PMid:29135601.

16. Samora M, Teixeira AL, Sabino-Carvalho JL, Vianna LC. Spontaneous cardiac baroreflex sensitivity is enhanced during post-exercise ischemia in men but not in women. Eur J Appl Physiol. 2019;119(1):103-11. http://doi.org/10.1007/s00421-018-4004-y. PMid:30293100.

17. Mayo X, Iglesias-Soler E, Carballeira-Fernández E, Fernández-Del-Olmo M. A shorter set reduces the loss of cardiac autonomic and baroreflex control after resistance exercise. Eur J Sport Sci. 2016;16(8):996-1004. http://doi.org/10.1080/17461391.2015.1108367. PMid:26568203.

18. Río-Rodríguez D, Iglesias-Soler E, Fernández del Olmo M. Set configuration in resistance exercise: muscle fatigue and cardiovascular effects. PLoS One. 2016;11(3):e0151163. http://doi.org/10.1371/journal.pone.0151163. PMid:26982500.

19. Beske SD, Alvarez GE, Ballard TP, Davy KP. Gender difference in cardiovagal baroreflex gain in humans. J Appl Physiol. 2001;91(5):2088-92. http://doi.org/10.1152/jappl.2001.91.5.2088. PMid:11641348.

20. Baechle T, Earle R. Essentials of strength training and conditioning. Champaign: Human Kinetics; 2000.

21. Parati G, di Rienzo M, Mancia G. How to measure baroreflex sensitivity: from the cardiovascular laboratory to daily life. J Hypertens. 2000;18(1):7-19. http://doi.org/10.1097/00004872-200018010-00003. PMid:10678538.

22. di Rienzo M, Parati G, Castiglioni P, Tordi R, Mancia G, Pedotti A. Baroreflex effectiveness index: an additional measure of baroreflex control of heart rate in daily life. Am J Physiol Regul Integr Comp Physiol. 2001;280(3):744-51. http://doi.org/10.1152/ajpregu.2001.280.3.R744. PMid:11171653.

23. Task Force of the European Society of Cardiology the North American Society of Pacing Electrophysiology. Heart rate variability: standards of measurement, physiological interpretation and clinical use. Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology. Circulation. 1996;93(5):1043-65. http://doi.org/10.1161/01.CIR.93.5.1043. PMid:8598068.

24. Parati G, Ochoa JE, Lombardi C, Bilo G. Assessment and management of blood-pressure variability. Nat Rev Cardiol. 2013;10(3):143-55. http://doi.org/10.1038/nrcardio.2013.1. PMid:23399972.

25. Dankel SJ, Mattocks KT, Jessee MB, Buckner SL, Mouser JG, Loenneke JP. Do metabolites that are produced during resistance exercise enhance muscle hypertrophy?

Eur J Appl Physiol. 2017;117(11):2125-35. http://doi.org/10.1007/s00421-017-3690-1. PMid:28776271.

26. Iellamo F, Hughson RL, Castrucci F, Legramante JM, Raimondi G, Peruzzi G, et al. Evaluation of spontaneous baroreflex modulation of sinus node during isometric exercise in healthy humans. Am J Physiol. 1994;267(3 Pt 2):994-1001. PMid:8092303.

27. Fisher JP, Young CN, Fadel PJ. Effect of muscle metaboreflex activation on carotid-cardiac baroreflex function in humans. Am J Physiol Heart Circ Physiol. 2008;294(5):2296-304. http://doi.org/10.1152/ajpheart.91497.2007. PMid:18326794.

28. Hartwich D, Dear WE, Waterfall JL, Fisher JP. Effect of muscle metaboreflex activation on spontaneous cardiac baroreflex sensitivity during exercise in humans. J Physiol. 2011;589(Pt 24):6157-71. http://doi.org/10.1113/jphysiol.2011.219964. PMid:21969452.