Impact of set configurations on hemodynamics, cardiac autonomic, and metabolic responses

Impacto de las configuraciones de los sets en las respuestas hemodinámicas, autonómicas cardíacas y metabólica

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Abstract

Introduction: Isometric exercise (IE) can be used as a non-pharmacologic treatment for blood pressure (BP) reduction. However, the effect of IE set configuration with impulse-to-rest ratio equated on hemodynamic, autonomic, and metabolic responses need to be clarified.
Objective: This study compared cardiovascular, autonomic, and metabolic responses in two set configurations of IE with an equalized impulse-to-rest ratio.
Methodology: Eleven women (25 ± 3 years old) with normal BP values (systolic BP: 112 ± 10 mmHg; diastolic BP: 71 ± 5 mmHg) performed two equalized protocols in the leg press machine on different days in randomized sequence: Long set configuration (LSC: 4 sets x 2 min of isometric contraction x 2 min of rest with 30% 1-RM), and short set configuration (SSC: 16 sets x 30 sec of isometric contraction x 24 sec of rest with 30% 1-RM).
Results: During SSC, DBP presented significantly higher values in the first set than LSC ($p=0.002$). Heart rate, rate pressure product, and cardiac output significantly increased during sets for both protocols. Twenty minutes after protocol, lower values were observed in the mean root square of the successive differences between NN intervals (RMSSD) and mean of the standard deviations for all NN intervals (SDNN) in the LSC configuration in comparison with SSC ($p<0.05$). In addition, LSC induced significantly higher blood lactate and RPE values during and post-session ($p<0.05$).
Conclusion: The SSC protocol can be better tolerated and targeted for exercise prescription in trained women due to lower hemodynamic, autonomic, and metabolic stress.

Keywords

Isometric exercise; heart rate; cardiac output; lactate.

Resumen

Introducción: El ejercicio isométrico (EI) puede utilizarse como un tratamiento no farmacológico para la reducción de la presión arterial (PA). Sin embargo, el efecto de la configuración del conjunto de EI con una relación impulso-descanso igualada en las respuestas hemodinámicas, autonómicas y metabólicas necesita ser aclarado.
Objetivo: Este estudio comparó las respuestas cardiovasculares, autonómicas y metabólicas en dos configuraciones de conjunto de EI con una relación impulso-descanso igualada.
Metodología: Once mujeres (25 ± 3 años) con valores normales de PA (PA sistólica: 112 ± 10 mmHg; PA diastólica: 71 ± 5 mmHg) realizaron dos protocolos igualados en la máquina de prensa de pierna en diferentes días en secuencia aleatoria: Configuración de conjunto largo (CCL: 4 conjuntos x 2 min de contracción isométrica x 2 min de descanso con 30% 1-RM), y configuración de conjunto corto (CCC: 16 conjuntos x 30 seg de contracción isométrica x 24 seg de descanso con 30% 1-RM).
Resultados: Durante el SSC, la PA diastólica presentó valores significativamente más altos en el primer conjunto que en el CCL ($p=0.002$). La frecuencia cardíaca, el producto de presión de la frecuencia y el gasto cardíaco aumentaron significativamente durante los conjuntos para ambos protocolos. Veinte minutos después del protocolo, se observaron valores más bajos en la raíz cuadrada media de las diferencias sucesivas entre los intervalos NN (RMSSD) y la media de las desviaciones estándar de todos los intervalos NN (SDNN) en la configuración CCL en comparación con CCC ($p<0.05$). Además, el CCL indujo valores significativamente más altos de lactato en sangre y de RPE durante y después de la sesión ($p<0.05$).
Conclusión: El protocolo CCC puede ser mejor tolerado y es más adecuado para la prescripción de ejercicio en mujeres entrenadas debido a un menor estrés hemodinámico, autonómico y metabólico.

Palabras clave

Ejercicio isométrico; frecuencia cardíaca; producto de presión; lactato.

Introduction

Isometric exercise (IE) is a powerful strategy to manage blood pressure (BP) for people with and without musculoskeletal limitations (Cornelissen and Smart 2013; Smart et al. 2019; Edwards et al. 2023). Some scientific evidence shows that IE could significantly reduce resting BP more than aerobic exercise and traditional resistance training (Cornelissen and Smart 2013; Edwards et al. 2023). Furthermore, significant reductions in systolic (SBP), diastolic blood pressure (DBP), and mean arterial pressure (MAP) were demonstrated in acute and chronic studies with normotensive and hypertensive people using the IE (Carlson et al. 2014; Inder et al. 2016; Edwards et al. 2023).
However, during resistance exercise, there is an increase in cardiovascular demand (SBP, DBP, MAP, heart rate (HR), rate pressure product (RPP)) (MacDougall et al. 1985; Iglesias-Soler et al. 2015; Río-Rodríguez et al. 2016), metabolic stress (Simões et al. 2010), and rating of perceived exertion (RPE) (Mayo et al. 2014; Río-Rodríguez et al. 2016; Paulo et al. 2019). These physiological adjustments are determined by the prescription of set configuration, which refers to the length of the sets (such as the number of repetitions or the isometric contraction time in each set) and how the total resting time is distributed within the set configuration (Iglesias-Soler et al. 2014; Reis et al. 2022). Thus, long set configurations (LSC), when compared to short set configurations (SSC, such as cluster-set configuration with short rest periods between clusters of repetitions), appear to induce a more significant increase in cardiovascular and metabolic demand, as well as a higher RPE during physical exercise, both in dynamic resistance exercise (Mayo et al. 2014, 2016b; Iglesias-Soler et al. 2015; Paulo et al. 2019; Rúa-Alonso et al. 2022), and IE (Río-Rodríguez et al. 2016).

Thus, when comparing the acute response during exercise, Iglesias-Soler et al. (2015) observed that LSC induces a significant increase in SBP, HR, and RPP compared to SSC during the parallel squat exercise. Consistent with the previous study, Paulo et al. (2019) observed that LSC increases SBP, HR, and RPP more than SSC during the knee extension machine. On the other hand, Rúa-Alonso et al. (2022) found no significant differences in hemodynamic variables between the different sets configurations, only observing a greater chronotropic response (HR and RPP) in the LSC compared to the SSC during the knee extension machine. In contrast to previous studies that utilized dynamic exercises for the lower limbs, Río-Rodríguez et al. (2016) employed IE in the knee extension. They observed a significant increase in HR and RPP only in the LSC. Furthermore, LSC results in a higher RPE than SSC (Mayo et al. 2014; Río-Rodríguez et al. 2016; Paulo et al. 2019).

Furthermore, studies investigating the cardiovascular, autonomic, and metabolic effects of different set configurations have found no hypotensive effect (SBP, DBP, and MAP), regardless of the set configuration (Xián Mayo, Iglesias-Soler, Carballeira-Fernández, & Fernández-Del-Olmo, 2016; Xián Mayo, Iglesias-Soler, Fariñas-Rodríguez, et al., 2016; Río-Rodríguez et al., 2016). However, it has been observed that LSC can induce maintenance in the increase in HR post-exercise compared to SSC, both in dynamic (Mayo et al. 2017; Rúa-Alonso et al. 2020) and IE (Río-Rodríguez et al. 2016). One possible explanation is the greater parasympathetic cardiac withdrawal and baroreflex sensitivity induced by the LSC (Mayo et al. 2016a; Río-Rodríguez et al. 2016; Rúa-Alonso et al. 2020), which has been negatively correlated with lactate levels (Simões et al. 2010). It has previously been shown that LSC induces greater lactate production than SSC (Paulo et al. 2019; Rúa-Alonso et al. 2020) being a greater lactate production positively correlated with greater perceived effort (Vargas-Molina et al. 2020). Most studies showing a higher hemodynamic have been performed with dynamic exercises, whereas only one study has explored this tendency for a monoarticular exercise (Río-Rodríguez et al. 2016). However, the differences between LSC and SSC with equated impulse-to-rest ratio regarding cardiovascular and metabolic responses to a lower limb multi-joint isometric exercise have not been explored yet. Therefore, we aimed to test the hypothesis that IE with an SSC will induce lower hemodynamic, cardiac parasympathetic, and metabolic response than a long set configuration.

Method

The present study is a cross-sectional, quasi-experimental study design. Initially, the sample consisted of 15 participants. Four participants were excluded throughout the experiment: three could not complete the three sets of LSC in an isometric contraction. In contrast, one participant started taking oral isotretinoin (Roacutan®) during the experiment, presented hemodynamic values above the reference values, and reported discomfort, presenting criteria for discontinuation (Menenghelo RS, Araújo CGS, Mastrocolla LE, Albuquerque `F 2010). As study inclusion criteria: normotensive women, aged between 20 and 30 years, without musculoskeletal injury or any chronic degenerative disease. Non-inclusion and exclusion criteria: not maintaining isometric contraction until the end of each set and not having musculoskeletal injuries that would prevent them from performing an exercise. All participants underwent screening and were excluded if they had a history of cardiovascular disease, were taking medications or substances that could affect the results, were unable to maintain isometric contractions until the end of each set, or had any musculoskeletal limitations that would prevent them from exercising.

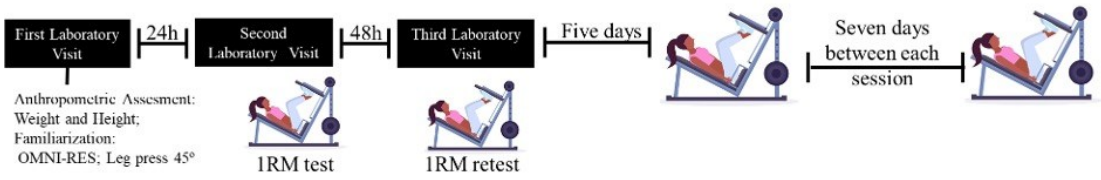
Thus, 11 normotensive physically active women were evaluated (age: 25 ± 3 years, height: 1.63 ± 0.07 m, body mass: 60.7 ± 6.0 kg, body mass index: 22.7 ± 1.3 kg/m2, SBP resting 112 ± 10 mmHg, DBP resting: 71 ± 5 mmHg, HR resting: 73 ± 11 bpm, Leg Pres 1RM: 249 ± 62 kg; 30% of 1RM: 75 ± 19 kg). The participants were instructed to abstain from any physical exercise during research and caffeine at least 3 hours before experimental sessions and abstain from ingesting alcohol 48 hours before experimental sessions. All of them were informed about the objectives, procedures, benefits, and possible risks of participation. After receiving information about the procedures, the participants signed the informed consent form. The study was approved by the Ethics and Research Committee of the Federal University of Espírito Santo (CAAE: 90076218.0.0000.5542/2018) and adhered to the ethical principles outlined in the Declaration of Helsinki.

Study design

The participants visited the laboratory on five different days. On the first visit, there was a detailed explanation of the project. Then, an anthropometric assessment of body mass and height was performed on a scale with a stadiometer attached (Welmy®, São Paulo, Brazil). Next, a resting BP assessment was performed (OMROM HEM7200) (Malachias MVB, Souza WKSB, Plavnik FL, Rodrigues CIS, Brandão AA, Neves MFT 2016). Afterward, familiarization with the rating of perceived exertion using the OMNI-RES scale (Lagally and Robertson 2006) and the inclined Leg Press machine was performed (Flex Fitness Equipment®, Capri, São Paulo, Brazil). During familiarization, participants performed in Leg Press, one set of ten dynamic repetitions and, after one minute of rest interval, two sets with 30 seconds of isometrics in a 90º angle of the knee joint, with the load corresponding to the equipment platform (23.6 kg).

On the second visit, 24 hours later, a one-repetition maximum (1RM) test was performed. Then, 48 hours later, a 1RM retest was performed on the third visit. Five days later, participants returned to the laboratory for the IE protocols. Both experimental sessions were separated by seven days (fourth and fifth lab visits) (Figure 1).

Figure 1. Schematic representation of study design. 1RM test: 1-repetition maximal test.



One-repetition maximum (1RM) test

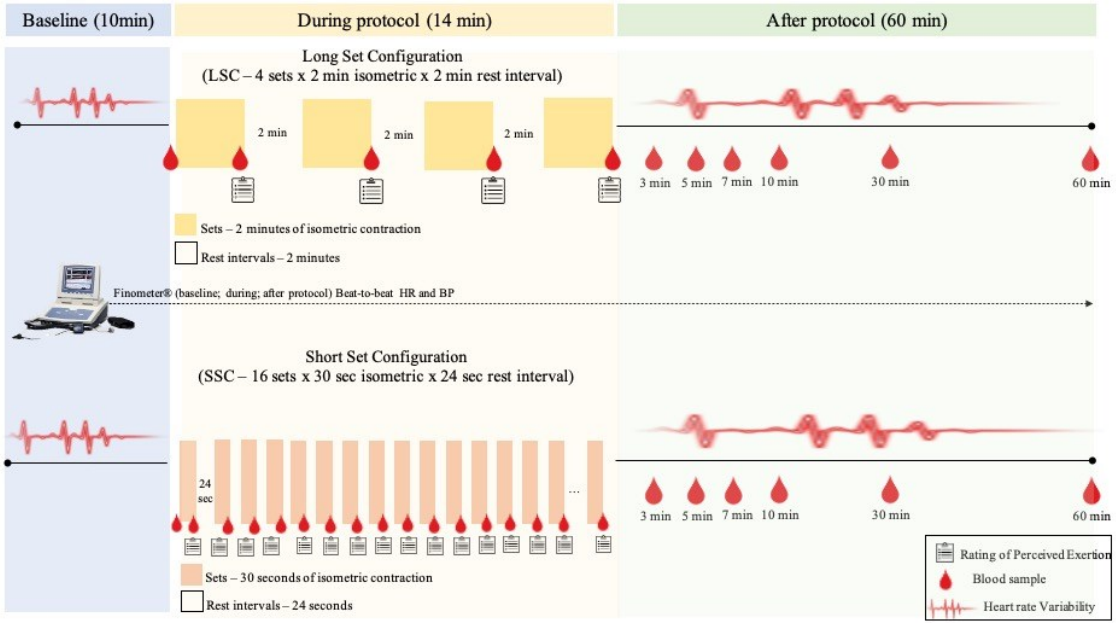
The 1RM test was conducted according to Triplett & Haff (Triplett 2016). The test started with the specific warm-up on the Leg Press, followed by ten repetitions (40% of the estimated 1RM, according to the 10 RM load auto-reported by each participant). After one minute of rest interval, participants performed a second set of five repetitions (60% of the estimated 1RM). Thus, two minutes after warm-up, the 1RM test was started. The test comprised a maximum of five attempts interspersed with at least 5 min of rest. 1RM was defined as the load a participant could lift correctly once but not twice. The 1RM retest was

applied after 48 hours. Intraclass correlation coefficient (ICC) two-way mixed effects were used to test the reliability of the 1RM (ICC = 0.838 [IC 95% = 0.320 – 0.960]).

Experimental sessions

The order of the IE protocols (long and short set configuration protocols – LSC and SSC, respectively) was randomly established with a seven-day interval between them. Sessions were performed at the same time of the day for each participant. Before starting the experiment, the knee joint angle was measured using clinical goniometry (Carci®, São Paulo, Brazil). It was established at 90º of knee flexion, and the position at which the participant should keep the device platform in contraction isometric was recorded. The test was stopped if the participant could not maintain the marked angle due to muscle failure. In addition, the participants were instructed to maintain a regular breathing pattern during exercise, avoiding the Valsalva maneuver. Both IE protocols entailed 480 seconds of isometric contraction, with 30% 1RM and a total rest interval of 360 seconds. The LSC protocol consisted of 4 sets of 2 min in isometric with 2 min rest intervals. The SSC protocol consisted of 16 sets of 30 sec in isometric with 24 sec rest intervals (Figure 2).

Figure 2. Schematic representation of set configurations and recovery analysis.



LSC (Long set configuration): 4 sets of 2 min of isometry with 2 min rest intervals; SSC (Short set configuration): 16 sets of 30 sec with 24-sec rest intervals; Block: refers to every four sets of the SSC. HR: heart rate; BP: blood pressure.

Physiological Recording

Cardiovascular parameters (SBP, DBP, MAP, HR, cardiac output (CO), and stroke volume (SV)) were collected continuously (baseline, during, and after protocols) non-invasively by photoplethysmography (Finometer®, Finapres Medical System BV, Netherlands). In addition, a three-lead electrocardiogram assessed heart rate (HR). After arrival at the lab, the participants remained seated in the Leg Press, with one arm cuff and another on the middle finger of the non-dominant hand. The electrodes were placed according to the manufacturer's recommendations (Finapres Medical System, Netherlands).

After Finometer calibration, baseline measurements were obtained for 10 minutes with the participant seated on the Leg Press Machine and feet positioned on the floor. Then, before starting the experiment, there was a detailed explanation of the protocol and all the procedures that would be performed (collection between sets of the RPE and blood lactate). Subsequently, cardiovascular parameters (SBP, DBP, MAP, HR, CO, and SV) were monitored during the protocols for 14 minutes and continued for 60 minutes after the protocols.

SBP, DBP, MAP, HR, CO, and SV data were extracted from BeatScope® software (Finapres Medical System BV, Netherlands) for Microsoft Excel® software. During the experimental sessions, the beginning

and end of each period were marked on BeatScope®, namely: baseline (10 min), during (14 min - demarcation made at the beginning and end of each set and rest), and after protocols (60 min - The participants remained seated at rest on the equipment). Data analysis was performed in each period marked on BeatScope® through the average of each variable. The calibration period and prior explanation of the protocols were excluded from the analysis. The rate pressure product (RPP) was calculated as the product between SBP and HR.

Pulse Intervals (ms) data were extracted and saved in a file extension for text files (txt.) and analyzed in Kubios HRV Standard 3.3.0® software for heart rate variability analysis (HRV). In Kubios HRV®, the indices were obtained using the linear time- and frequency-domain analysis method. Corrections were applied up to the strong threshold to filter out artifacts, with no more than 5% filtering. It was collected 10 min at baseline and 60 min post-protocols. The first and last two minutes before exercise were excluded for rest analysis, leaving seven minutes. The first minute was removed to ensure signal stabilization, and the last two minutes of rest to avoid the influence of the anticipatory effect of exercise. For post-exercise recovery analysis, the time was divided into six 10-minute periods.

The analyses were made from linear time domain: rMSSD (the square Root of the mean squared differences of successive R-R intervals) and SDNN (Standard deviation of the normal-to-normal interval). In addition, the frequency domain (spectral analysis) was analyzed: low frequency (LF- sympathetic and parasympathetic component), high frequency (HF – Parasympathetic component), and the ratio LF/HF representing the sympathovagal balance (Jelinek et al., 1996; Aubert et al., 2003). The spectral analysis was calculated using the Fast Fourier Transform method in the normalized unit (nu) (Jelinek et al., 1996; Aubert et al., 2003).

Blood Lactate Concentration

Blood samples (25µL) were collected from the earlobe with capillary (Perfecta®) before, after each set, immediately after IE protocols, and at 3, 5, 7, 10, 30, and 60 minutes after the protocols. Blood lactate concentration was analyzed by electrochemical lactimeter YSI2300 STAT Plus® (Yellow Springs, Ohio, USA).

Rating of Perceived Exertion

After each set, RPE was assessed using the OMNI-RES (Valid scale for monitoring and controlling perceived exertion in strength exercises - Lagally and Robertson 2006) scale through the question: “How did you perceive your effort during exercise?”.

Data analysis

All data were tabulated and double-verified by independent researchers. First, the normality was tested using the Shapiro-Wilk test. When data violated the normality assumption, natural logarithmic (base e) transformation and the normality test were applied. Intraclass Correlation Coefficients (ICC) two-way mixed effects were used to establish the reliability of the 1RM test. The reference values for the ICC were < 0.5 (poor), 0.5–0.75 (moderate), 0.75–0.90 (good), and 0.90 (excellent) (Koo and Li 2016). For protocol comparison, a block was considered for every four sets of the SSC protocol. Thus, a two-way repeated measures ANOVA (protocol x time) was performed to evaluate the effect and interaction between protocols (LSC and SSC) and time (baseline, during, and after protocols) for SBP, DBP, MAP, HR, RPP, CO, and SV. The same statistical procedure was adopted for HRV (baseline and after protocols) and blood lactate (baseline, during, and after protocols). Post-hoc comparisons were performed with the Bonferroni correction. For RPE, non-parametric Friedman’s tests were used with the Wilcoxon signed-rank tests for post hoc comparisons. Mauchly's test was used to evaluate sphericity. If this assumption was violated, degrees of freedom Greenhouse-Geisser correction was applied. Partial eta-squared ($p\eta 2$) was utilized as a measure of effect size in ANOVA, using small ($p\eta 2 = 0.01$), medium ($p\eta 2 = 0.06$), and large ($p\eta 2 = 0.14$) effects as references values (Lakens 2013). Statistical significance was established with a $p \leq 0.05$. The data were analyzed using SPSS 25.0 (SPSS, Inc., Chicago, USA).

Results

Baseline values did not present significant differences between sessions for any variable ($p > 0.05$).

Cardiovascular responses during the protocols are shown in Table 1. Interaction between time*protocol were observed only for HR [F(2.34, 23.41) = 12.195; p < 0.001; pη2 = 0.549] and CO [F(2.04, 20.46) = 5.032; p < 0.016; pη2 = 0.334]. For HR, higher values were observed during sets/blocks 1, 2, 3, and 4 for LSC compared to SSC (p < 0.001 for all). For CO, higher values were observed during sets/blocks 2, 3, and 4 in LSC than in SSC (p = 0.026; p = 0.026; p = 0.008, respectively).

Table 1. Cardiovascular response during LSC and SSC protocols.

	Baseline	Set/Block 1	Set/Block 2	Set/Block 3	Set/Block 4
SBP (mmHg)					
LSC	120±11	149±16[a]	157±15[a]	160±13[a,b]	162±13[a,b]
SSC	121±8	154±13[a]	166±16[a,b]	168±16[a,b]	169±16[a,b]
DBP (mmHg)					
LSC	68±6	93±7[a]	98±7[a,b]	101±6[a,b]	103±6[a,b]
SSC	70±7	106±15[a,e]	105±11[a]	107±12[a]	108±12[a]
MAP (mmHg)					
LSC	89±7	118±11[a]	125±11[a,b]	128±9[a,b]	129±9[a,b]
SSC	91±7	122±12[a]	132±13[a,b]	134±14[a,b]	134±13[a,b]
HR (bpm)					
LSC	77±12	114±18[a]	122±21[a]	134±22[a,b,c]	142±22[a,b,c,d]
SSC	76±11	102±16[a,e]	108±18[a,e]	116±23[a,e]	120±26[a,e]
CO (L·min^{-1})					
LSC	6.0±1.4	8.4±1.8[a]	8.6±1.7[a]	9.0±2.0[a]	9.5±2.0[a]
SSC	6.0±1.2	7.7±1.7[a]	7.6±1.7[e]	7.8±1.9[e]	7.8±1.9[a,e]
SV (ml)					
LSC	78.6±12.1	74.4±10.5	71.8±9.4	68.7±10.3	67.4±9.7
SSC	78.9±12.4	76.2±14.8	71.4±14.6	68.1±14.9	65.9±14.2

Mean ± standard deviation; LSC: Long set configuration; SSC: Short set configuration; SBP: Systolic blood pressure; DBP: Diastolic blood pressure; MAP: Mean arterial pressure; HR: Heart rate; CO: Cardiac output; SV: stroke volume; Block 1 (sets 1, 2, 3, and 4); Block 2 (sets 5, 6, 7, and 8); Block 3 (sets 9, 10, 11, and 12); Block 4 (sets 13, 14, 15, and 16); (p≤0.05). [a]Significant difference versus baseline; [b]Significant difference versus set/block 1; [c]Significant difference versus set/block 2; [d]Significant difference versus set/block 3; [e]Significant difference between LSC versus SSC.

The cardiovascular response values post-exercise are shown in Table 2. Interactions between time*protocol were observed in HR [F(2.34, 23.41) = 12.195; p < 0.001; pη2 = 0.549] and CO [F(2.04, 20.46) = 5.032; p < 0.016; pη2 = 0.334]. For HR, higher values were observed in LSC compared to SSC at 10, 20, 30, 40, 50, and 60 minutes (p = 0.007; p = 0.007; p = 0.008; p = 0.004; p = 0.023; p = 0.008, respectively). Similarly, higher values were observed for CO at 10 and 20 minutes (p = 0.005; p = 0.021, respectively) for LSC compared to SSC.

Table 2. Cardiovascular response before (baseline) and after LSC and SSC protocols.

	Baseline	10 min	20 min	30 min	40 min	50 min	60 min
			SBP (mmHg)				
LSC	120±11	119±12	116±9	119±7	123±9	123±9	125±11
SSC	121±8	122±13	123±12[e]	131±16	129±12	130±11	131±11
			DBP (mmHg)				
LSC	68±6	67±8	68±7	70±7	72±7	72±6	74±7[b]
SSC	70±7	71±7[e]	72±7[e]	74±7	76±6[b]	77±6	78±6[a,b]
			MAP (mmHg)				
LSC	89±7	87±9	86±8	89±8	92±8[c]	92±8[c]	94±9
SSC	91±7	91±9	92±9[e]	95±9	97±9[c]	99±8[e]	100±8[a,b,c]
			HR (bpm)				
LSC	77±12	102±19[a]	91±16[a,b]	90±14[a,b]	87±15[a,b]	85±14[a,b,c,d]	84±14[a,b,d]
SSC	76±11	92±17[a,e]	83±13[b,e]	83±13[a,e]	80±13[b,e]	80±13[b,c,d,e]	79±12[b,c,e]
			CO (L·min^{-1})				
LSC	6.0±1.4	7.9±2.2	6.6±1.2	6.3±1.1	6.2±1.1	6.2±1.2	6.0±1.2
SSC	6.0±1.2	6.8±1.5[e]	6.1±1.2[e]	6.2±1.2	6.0±1.3	6.0±1.2	5.9±1.1
			SV (ml)				
LSC	78.6±12.1	77.7±14.7	72.0±5.6	70.9±6.5	71.9±7.8	73.0±8.1	72.6±9.3
SSC	78.9±12.4	74.4±13.7	74.3±10.4	75.5±9.8	75.0±11.6	75.7±10.4	75.0±12.2

Mean ± standard deviation; LSC: Long set configuration; SSC: Short set configuration;SBP: Systolic blood pressure; DBP: Diastolic blood pressure; MAP: Mean arterial pressure; HR: Heart rate; CO: Cardiac output; SV: stroke volume; (p≤0.05). [a]Significant difference versus baseline; [b]Significant difference at 10 min post-protocol; [c]Significant difference at 20 min post-protocol; [d]Significant difference at 30 min post-protocol; [e]Significant difference between LSC versus SSC.

For HRV, there was an interaction between time*protocol for RMSSD [F (2.70, 27.02) = 3.173; p = 0.044; pη2 = 0.240] and SDNN [F (6.00, 60.00) = 2.455; p = 0.034; pη2 = 0.197] (Table 3). LSC showed lower RMSSD and SDNN values at 20 minutes than SSC (p = 0.009; p = 0.008, respectively).

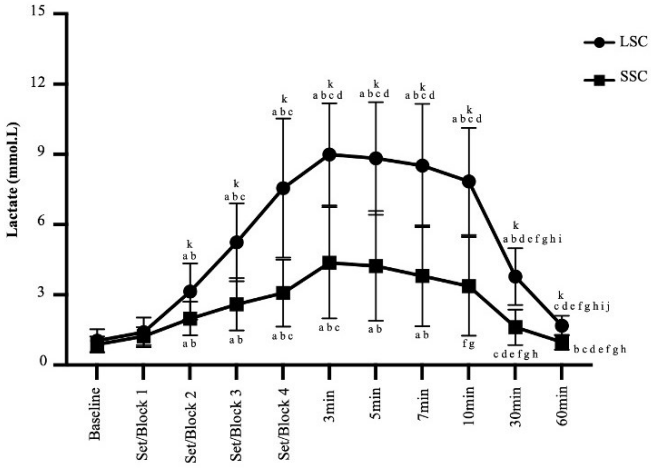
Table 3. Heart Rate Variability results at baseline and after LSC vs. SSC.

	Baseline	10 min	20 min	30 min	40 min	50 min	60 min
				LF (nu)			
LSC	59.69±12.66	71.28±14.03	74.08±14.58	71.62±18.29	70.58±17.00	69.54±16.39	68.73±15.87
SSC	54.10±16.24	72.33±10.70	71.77±11.54[a]	71.70±9.94[a]	67.21±11.60	68.52±12.55	65.13±15.43
				HF (nu)			
LSC	40.15±12.72	28.55±14.04	25.85±14.56	28.29±18.31	29.36±17.00	30.40±16.38	31.19±15.90
SSC	45.73±16.41	27.49±10.71	28.05±11.45[a]	28.24±9.92[a]	32.65±11.64	31.38±12.51	34.77±15.45
LF/HF							
LSC	1.69±0.74	3.28±1.97	4.42±3.28	4.48±3.75	3.42±2.16	3.31±2.29	3.02±2.00
SSC	1.57±1.32	3.07±1.35[a]	3.11±1.56	2.87±1.11[a]	2.39±1.07	2.59±1.21	2.45±1.68
				Ln RMSSD (ms)			
LSC	3.68±0.36	2.92±0.52[a]	3.05±0.50[a]	3.22±0.54	3.34±0.51	3.43±0.50[b,c,d,e]	3.52±0.50[b,c,d,e,f]
SSC	3.66±0.36	3.14± 0.45[a]	3.32±0.48[g]	3.45±0.37[b]	3.55±0.39[b]	3.61±0.43[b,c]	3.64±0.39[b]
				SDNN (ms)			
LSC	44.41±12.3	24.18±11.65[a]	30.54±11.21	37.58±14.52[b]	41.76±15,48[b]	43.23±14.98[b,c]	47.27±18.73[b,c]
SSC	42.53±10.21	30.58±11.73	37.73±14.74[g]	42.85±10.89[b]	44.49±14,67	48.51±15.84	48.12±12.2[b]

Mean ± standard deviation; LSC: Long set configuration; SSC: Short set configuration; LF: low frequency in normalized units; HF: high frequency in normalized units; LF/HF: LF to HF ratio; Ln RMSSD: natural logarithmic of Root of the mean squared differences of successive NN intervals; SDNN: Standard Deviation of the NN Interval; (p≤0.05). [a]Significant difference versus baseline; [b]Significant difference at 10 min post-protocol; [c]Significant difference at 20 min post-protocol; [d]Significant difference at 30 min post-protocol; [e]Significant difference at 40 min post-protocol; [f]Significant difference at 50 min post-protocol; [g]Significant difference between LSC versus SSC.

For lactate, there was an interaction between time*protocol [F(2.20, 22.01) = 20.906; p < 0.001; pη2 = 0.676] (Figure 4). LSC showed higher lactate values in sets/blocks 2, 3, and 4 compared to SSC (p < 0.015; p < 0.001; p < 0.001, respectively). Post-exercise, lactate remained higher at 3, 5, 7, 10, 30, and 60 minutes in the LSC compared to the SSC (p < 0.001 for all) (Figure 3).

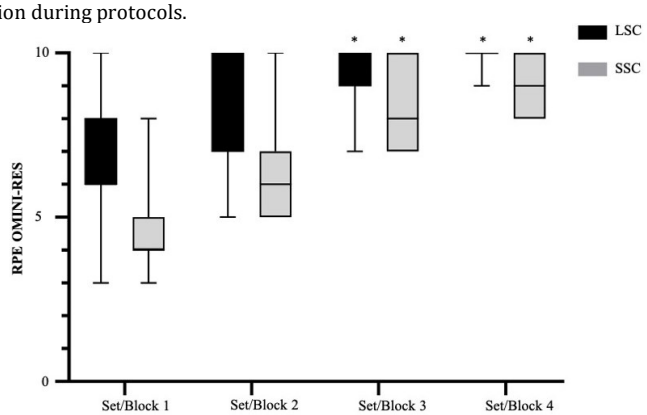
Figure 3. Lactate concentration was measured before, during, and after protocols. LSC vs. SSC; (p≤0.05).



LSC: Long set configuration; SSC: Short set configuration; [a]Significant difference versus baseline; [b]Significant difference versus set/block 1; [c]Significant difference versus set/block 2; [d]Significant difference versus set/block 3; [e]Significant difference versus set/block 4; [f]Significant difference at 3 min post-protocol; [g]Significant difference at 5 min post-protocol; [h]Significant difference at 7 min post-protocol; [i]Significant difference at 10 min post-protocol; [j]Significant difference at 30 min post-protocol; [k]Significant difference between LSC versus SSC.

For RPE (OMNI-RES), the Friedman test showed that the RPE values differed in the protocols [X2(7) = 58.434; p < 0.001]. LSC, RPE values were higher in set 3 and 4 compared to set 1 (p = 0.009 and p = 0.001, respectively). Similarly, RPE values were higher in sets 3 and 4 than in set 1 in SSC (p = 0.010 and p < 0.001, respectively) (Figure 4).

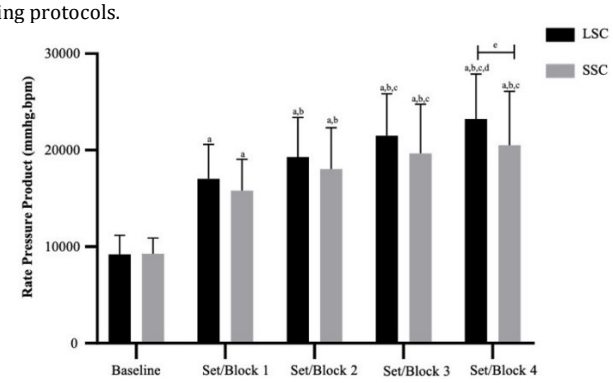
Figure 4. Rating of Perceived Exertion during protocols.



RPE: Rating of Perceived Exertion; LSC: Long set configuration; SSC: Short set configuration; (p≤0.05). *Significant difference versus set/block 1.

No interaction between time*protocol were observed for SBP [F(1.53, 15.37) = 0.761; p > 0.451; pη2 = 0.070], DBP [F(1.64, 16.47) = 1.732; p > 0.209; pη2 = 0.147], MAP [F(1.50, 15.03) = 0.337; p > 0.658; pη2 = 0.032], SV [F(2.08, 20.82) = 1.292; p = 0.296; pη2 = 0.114], RPP [F(1.47, 14.78) = 3.422; p > 0.071; pη2 = 0.254] (Figure 5), LF(nu) [F(6.00, 60.00) = 0.570; p > 0.751; pη2 = 0.054], HF(nu) [F(6.00, 60.00) = 0.565; p > 0.755; pη2 = 0.053], and HF/LF [F(2.10, 21.07) = 1.484; p > 0.249; pη2 = 0.129).

Figure 5. Rate pressure product during protocols.



LSC: Long set configuration; SSC: Short set configuration; (p≤0.05); [a]Significant difference versus baseline; [b]Significant difference versus set/block 1; [c]Significant difference versus set/block 2; [d]Significant difference versus set/block 3; [e]Significant difference between LSC versus SSC.

Discussion

The present study aimed to investigate the acute effects of two IE set configurations with impulse-to-rest ratio equated on hemodynamic, cardiac autonomic modulation, and metabolic responses in normotensive young women. Our main findings were: (1) LSC induced greater cardiovascular demand with increases in HR, CO, and RPP throughout sets; (2) no hypotensive effect was observed after protocols; (3) LSC induced more significant metabolic stress during and after protocol compared to SSC. The results demonstrated that both IE protocols progressively increased SBP, DBP, and MAP values.

Isometric action involves maintaining muscle contraction, which increases intramuscular pressure, reduces local blood flow, and promotes muscle ischemia and hypoxia (MacDougall et al. 1985; Williams et al. 2007). However, the additive effect of alterations during IE generates a reflex response through muscle mechanoreceptors, chemoreceptors, and baroreceptors. It may increase sympathetic activity, demonstrated by higher HR and BP in the LSC than in the SSC (Iglesias-Soler et al. 2015; Río-Rodríguez et al. 2016). In this sense, Iglesias-Soler et al. (2015) observed a significant increase in SBP over the three sets in the parallel squat exercise compared to baseline in the traditional protocol (3 sets x muscle failure: 180sec [360sec]; 4RM). In the cluster protocol (same number of repetitions as in the traditional protocol: 360sec distributed between each repetition; 4RM), a significant increase was observed only at set 1 compared to baseline. In addition, the traditional configuration induced significant increases in SBP compared to the cluster protocol at sets 2 and 3. On the other hand, Río-Rodríguez et al. (2016)

observed an increase in SBP, DBP, and MAP during traditional (4 sets x 80% of the time to failure for 50% of MVC: 180sec[540sec]) and intra-set rest (16 sets x 20% of the time to failure for 50% of MVC: 36sec between each repetition [540sec] - cluster) in isometric knee extension machine. In contrast to the previous data, Rúa-Alonso et al. (2022) observed only one difference between the protocols for chronotropic parameters, where the LSC induced more significant increases in HR and RPP compared to the SSC.

Our findings corroborate the above studies, where a significant increase in HR was observed throughout the sets compared to the baseline in LSC and SSC. Considering the sustained increase in HR observed in this study, it was found that both frequency and time domain indices (HF and RMSSD), representing the cardiac parasympathetic modulation, remained reduced for 60 minutes after both LSC and SSC protocols compared to baseline. On the other hand, we can observe that the LF and LF/HF indexes remained high. In addition, there was a significant increase in CO during the protocols, especially in LSC, showing a significant difference between protocols in the final sets/blocks. This possible cardiovascular compensation mechanism can occur during longer sets (Iglesias-Soler et al. 2015; Río-Rodríguez et al. 2016) due to increased peripheral vascular resistance, SNS activity, and reduced blood perfusion in contracting skeletal muscles (Williams et al. 2007; Elstad et al. 2009).

The SV values during protocols did not present a significant difference. This result can be explained by the load percentage used in the protocols (30% of 1 RM). Pollock et al. (2000) and Williams et al. (2007) demonstrated that isometric action with lower than 50% maximal voluntary contraction (MVC) did not modify the SV values. However, the SV values tend to decrease with intensity when using a load higher than 50% of MVC and for a long time under tension (MacDougall et al. 1985).

Moreover, RPP is an indirect marker of cardiac effort and myocardial oxygen demand during exercise, directly related to effort, volume, rest interval, and the set configurations (Mayo et al. 2014; Iglesias-Soler et al. 2015; Río-Rodríguez et al. 2016). The present study observed a significant increase in both protocols, mainly in the final set/blocks. The LSC protocol induced higher values, corroborating the results observed by Río-Rodríguez et al. (2016) (IE in the knee extension machine), Iglesias-Soler et al. (2014) (dynamic parallel squat), Paulo et al. (2019) (dynamic knee extension machine), and Rúa-Alonso et al. (2022) (dynamic knee extension machine). The present study was the first to use the bilateral leg press exercise and IE, which involves large muscle mass and induces higher metabolic stress.

RPE was significantly higher at the end of the protocols (sets/blocks 3 and 4) than set/block 1. Unlike our findings, previous studies observed that LSC induced significant increases in RPE values compared to SSC (cluster or intra-set rest) (Mayo et al. 2014; Río-Rodríguez et al. 2016; Paulo et al. 2019). The literature shows increased RPE strongly correlates with perceived peripheral fatigue (Río-Rodríguez et al. 2016). In addition, no post-exercise hypotension was observed after either protocol, corroborating a previous study that did not observe hypotension in any set configurations (Mayo et al. 2016a). However, Mayo et al. (2016b) observed that SBP and DBP were lower post-exercise than in the control session in the protocol to failure.

The limitations of the present study include the lack of control for the menstrual cycle, which may influence certain hemodynamic and cardiac autonomic variables. The sample consisted only of normotensive subjects. Maximum isometric strength assessment was not performed to prescribe the intensity of the protocols. A control session is necessary to establish a baseline for temporal trends in cardiovascular variables. Thus, we emphasize caution in generalizing the results to populations with comorbidities, as this study involved a small number of participants who were young, normotensive, and physically active. Therefore, future studies should focus on analyzing the applicability of IE and different set configurations to develop a prescription guideline and promote BP benefits.

The results of this study indicated that the LSC protocol elicited greater cardiovascular and metabolic demand, regardless of the equalized impuse-to-rest ratio. In contrast, SSC can be an exciting strategy for people with low IE and/or LSC tolerance.

Conclusions

LSC presented higher cardiovascular, metabolic, and perceived exertion demand than SSC. Isometric exercise protocols in SSC structure are better tolerated and can be targeted for exercise prescription in trained women.

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