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EDUCAÇÃO FÍSICA / PHYSICAL EDUCATION

The influence of the order between resistance and stretching exercises on the hemodynamic response

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ABSTRACT. The present study compared the acute effect of different combinations of resistance training (RT) and static stretching (SS) on the heart rate (HR), rate pressure product (RPP) and oxygen saturation (SpO_2) of participants. This is a cross-over methodological design carried out in five visits on non-consecutive days, which always occurred at the same time of day. Twelve trained young men were randomly divided, using counterbalanced and alternate assignments, into three experimental situations: a) horizontal abduction of the shoulder, knee flexion and hip abduction before the bench press and leg extension machine, respectively (SS + RT); b) bench press and leg extension machine before horizontal abduction of shoulder, knee flexion and hip abduction, respectively (RT + SS); c) bench press and leg extension machine, exclusively (RT). Analysis of variance (ANOVA) with repeated measures showed significant differences in the SS+RT group when the variables were compared at rest (pre) and immediately after the exercises (post): HRpre *vs.* HRpost ($p = 0.000$) and RPPpre *vs.* RPPpost ($p = 0.000$). In the intergroup comparisons, significant differences were detected between the SS+RT and RT+SS experimental situations exclusively during the post period for the RPP ($p = 0.041$) and SpO_2 variables ($p = 0.002$). The combined use of SS and RT significantly changed the intragroup cardiovascular responses by increasing the HR and RPP and decreasing the SpO_2. However, the values were lower in the intergroup comparisons when the stretching exercises were performed both before and after RT, although no significant differences were found from a cardiovascular safety point of view.

Keywords: heart rate; blood pressure; cardiovascular system; resistance training; stretching; strength.

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Introduction

The American College of Sports Medicine (ACSM, 2011) suggests that strength and flexibility are key components for good physical fitness and therefore should be included in any physical activity and health-related quality of life program. Satisfactory levels of flexibility and strength are essential not only for developing and maintaining health and functionality but also for performing daily activities and sports movements effectively (ACSM, 2011).

Muscle stretching is commonly performed before and after resistance training (RT) and is typically used as a practice that improves performance and reduces the risk of injury (Sekir, Arabaci, Akova, & Kadagan, 2009; Jamtvedt et al., 2010). However, recent publications have questioned the concurrent use of muscle stretching and RT (Williams et al., 2007; Costa e Silva et al., 2012; Costa, Herda, Herda, & Cramer, 2014; Silva et., 2018). Stretching and RT should be included in the exercise routine of different populations, despite their concurrent effects (Williams et al., 2007; ACSM, 2011).

Understanding the physiological responses and hemodynamic oscillations is extremely valuable for training guidance and recommendations. Muscle oxidative capacity and the oxygen supply are impaired during stretching. Muscle stretching can reduce the caliber of blood vessels, leading to increased blood pressure (Farinatti, Soares, Monteiro, Duarte, & Castro, 2011) (BP), decreased blood flow, and consequently, reduced muscle oxygen saturation (Mitchell, 1990; Poole, Musch, & Kindig, 1997; McCully, 2010; Costa e Silva et al., 2013) (SpO_2). Accordingly, a hypoxic state may be linked to changes in autonomic responses that ensure homeostatic protection (American College of Sports Medicine [ACSM], 2007; Taaffe, Galvao, Sharman, & Coombes, 2007; Billaut & Smith, 2010). However, variations in the heart rate (HR) response as a function of performing stretching exercises and RT are still underreported in the literature (Farinatti et al., 2011; Majock, Kim, Eccles, & Panton, 2011). Accordingly, although studies (McCartney, 1999; Farinatti & Assis, 2000; Polito & Farinatti, 2003; Simão, Polito, & Lemos, 2003) have analyzed the effect of RT on the rate pressure product (RPP), few studies have analyzed such variables in combination with static stretching (SS) (Santos et al., 2014). Similarly, the only studies to date that have analyzed the effects of muscle stretching on SpO_2 were those of McCully (2010) and Costa e Silva et al. (2013).

Material and methods

Sample

A total of 12 young men (22.5 ± 4.2 years; 76.4 ± 2.8 Kg; 173.7 ± 9.2 cm; BMI 25.3 ± 3.3 kg m^{-2}) volunteered for the experiment, in October of 2013.

All participants freely signed the Informed Consent Form according to Resolution 466/12 of the National Health Council. The research project was submitted to and approved by the Research Ethics Committee of the *Universidade Federal Rural do Rio de Janeiro* (protocol n° 23083.011633/2011-37). Individuals with at least two years of experience in RT and who were medically cleared for physical evaluation were included. The following exclusion criteria were adopted: having an injury or strength training limitations; a history of upper-limb injuries; hypermobility or hypomobility; habitual use of tobacco.

Experimental procedures

The present study has cross-over methodological design and was performed during a total of five visits on non-consecutive days that always occurred at the same time of day. The individuals were subjected to an anthropometric assessment and the ten-repetition maximum (10RM) test for the bench press and leg extension machine exercises during the first visit. The 10RM retest was performed during the second visit (both exercises showed excellent reproducibility between the test and retest values, with values ranging from 0.90 to 0.99).

The participants were randomly divided, using counterbalanced and alternate assignments, into three experimental situations (Figure 1) performed from the third to the fifth visits including: a) horizontal abduction of the shoulder, knee flexion and hip abduction before the bench press and leg extension machine, respectively (SS + RT); b) bench press and leg extension machine before horizontal abduction of shoulder, knee flexion and hip abduction, respectively (RT + SS); c) bench press and leg extension machine, exclusively (RT).

10RM test

The following strategies were adopted to reduce the margin of error in the 10RM test. Standardized instructions were given, and prior volunteer familiarization with the test was performed to ensure that all volunteers assessed would be aware of the entire routine involved in the data collection process. The volunteers assessed were instructed on the technique of performing the bench press and leg extension machine exercises, and attention was paid to the position adopted by the subject when performing the measurement because small variations in the position of the joints involved in the movement could activate other muscles, leading to misinterpretations of the scores assessed. Verbal stimuli were used to maintain a high level of stimulation, and the additional weights used were previously calibrated with a precision scale. The angle of performance of the exercises was established and visually checked, and the evaluators were attentive in maintaining the same pattern of movement in the same individual between tests and training sessions. Three to five attempts were performed per exercise, and the interval between attempts in each exercise during the test was set at five minutes. The attempts were performed until momentary concentric failure occurred. After assessing the exercise load, a 20-minute interval was allowed before beginning the following exercise. The recommendation proposed by the ACSM (2007) was used for the 10RM test protocol and included a specific warm-up, wherein five to 10 repetitions with loads of 40 to 60% of the perceived maximum were performed before the first exercise. Following a one-minute interval, a load ranging from 60 to 80% of the perceived maximum was determined, and the volunteers assessed were instructed to perform six repetitions. After another one-minute interval, the load was slightly increased, and the subjects were instructed to perform the 10RM test. Forty-eight hours after the first day, a retest was performed to assess the reproducibility of the maximum load (10RM).

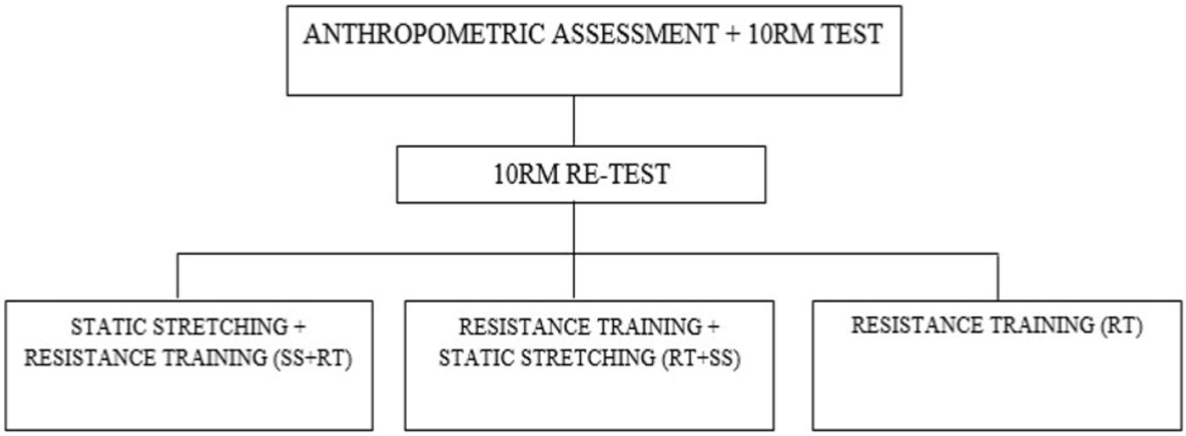

Figure 1. Experimental design.

Stretching protocol

The stretching protocol consisted of two 30-second sets of SS of the pectoral and quadriceps muscles with a 40-second interval between sets, wherein the range of motion of the joint was pushed to the point of discomfort (ACSM, 2011). The evaluation of the point of mild discomfort was performed subjectively by self-report of the volunteers. The pectoral stretching was performed passively, and the position adopted consisted of performing a 90º shoulder horizontal abduction (Costa e Silva et al., 2013). The same procedure was applied for quadriceps muscle stretching, in which the individuals remained in the prone position with the hip stabilized. Knee flexion and hip extension were performed to the maximum point of discomfort (Gomes, Simão, Marques, Costa, & Novaes, 2011). These exercises were performed bilaterally.

Resistance training protocol

The RT protocol consisted of performing three sets of 10 repetitions of bench presses with free weights and leg extension machine exercises. The intensity was adjusted to 80% of the 10RM value for both exercises and two-minute rest intervals were given between sets and between exercises.

Heart rate, systolic blood pressure, and the rate pressure product

The data for the HR analysis were collected using a heart rate monitoring watch (Polar, RS 800 CX, USA). The electrode was moistened and positioned on the sternum at the height of the xiphoid process. Data were collected, transferred onto a microcomputer through a Polar® infrared interface, processed using the Polar Precision Performance® software (Finland), and stored on a microcomputer for analysis. The HR was measured at rest (pre) and immediately after (post) the different experimental situations.

Determination of systolic blood pressure (SBP) values was performed via ambulatory blood pressure monitoring (ABPM; Burdick 90217 Ultralite, USA) using the oscillometric method to measure the SBP and diastolic blood pressure (DBP), thus enabling an automatic/manual recording of pressure values. The SBP was measured at rest and immediately after the different experimental situations.

The RPP calculation was performed by multiplying the results assessed in the HR and SBP measurements.

Oxygen saturation

A finger pulse oximeter (Nonin Onyx 9500, USA) was used to assess the SpO_2 values. Finger pulse oximetry is considered an indirect method of measuring oxygen consumption, and the values of the oxygen partial pressure obtained by this method show a correlation of $r = 0.98$ between the percentage of the partial pressure of oxygen (SpO_2) and the oxyhemoglobin values (HbO_2; 1.32% normal estimation error and $p < 0.0001$). The probe was placed on the index finger of the dominant hand, which was resting on a fixed surface for stabilization, to collect the data. The SpO_2 was measured at rest (pre) and immediately after the different experimental situations.

Statistical analysis

The sample size was estimated using the *G*Power* 3.1 software. Furthermore, we adopted a power of 0.80, α of 0.05, correlation coefficient of 0.5, nonsphericity correction of 1, and a size effect of 0.35, based on an a priori analysis. Thus, an N of 12 individuals was calculated. The sample size was sufficient to provide 83.3% of statistical power. The procedures suggested by Beck (2013) were adopted to calculate the sample size.

The Shapiro-Wilk test showed normality of the data obtained in the study. The limit of reproducibility between the test and retest sessions was analyzed using the intraclass correlation coefficient (ICC). A paired t-test was run to analyze the significant differences between the test and retest values. ANOVA with repeated measures was applied to determine differences in the HR, RPP, and SpO_2 changes following the experimental situations. Subsequently, a Bonferroni *post hoc* test was performed. Statistical analyses were performed using the statistical package for the social sciences (SPSS) 20.0 software (SPSS Inc., Chicago, IL, USA). A critical level of significance of $p < 0.05$ was adopted for all analyses.

Results and discussion

Significant differences were detected in the SS+RT group when the following time periods were compared for variables in the intragroup comparisons: HRpre vs. HRpost (70.08 ± 2.71 vs. 93.08 ± 2.32, $p < 0.001$), RPPpre vs. RPPpost (8,205.17 ± 884.77 vs. 11,218.92 ± 1,137.30, $p < 0.001$) (Table 1).

Significant differences were found, exclusively after the exercises were performed, in the intergroup comparisons (Table 1) when the SS+RT vs. RT+SS experimental situations were compared for the RPP (11,218.92 ± 1,137.30 vs. 10,303.30 ± 794.38, p = 0.041) and SpO2 variables (96.00 ± 0.54 vs. 90.33 ± 0.82, p = 0.002).

This study compared the acute effect of the order of RT and stretching (RT + SS vs. SS + RT) on the HR, SBP, RPP, and SpO_2 of participants. Our findings demonstrated that the concurrent use of RT and SS can significantly alter cardiovascular responses by increasing the HR and RPP. Thus, the inclusion of stretching exercises concurrent with RT increases the training workload, which may result from the association with a lower oxygen supply due to blood vessel occlusion (McCully, 2010; Costa e Silva et al., 2014) and acute post-stretching strength loss (Costa e Silva et al., 2012; 2013).

The present study demonstrates that the SS performance may present a lower cardiac overload as measured by the RPP response. However, when the RT + SS was compared with the protocol that only performed the RT, significant reductions were observed for that of the BP as well as the behavior of the RPP. The mechanisms involved in reducing BP after RT implies a reduction in peripheral vascular resistance that facilitates venous return, thus increasing the final ejection volume (American College of Sports Medicine [ACSM], 2004; Figueiredo et al., 2014). On the other hand, static stretching (SS), depending on the volume and intensity of exercise, promotes an increase in heart rate (HR) due to the activation of muscle mechanoreceptors sensitive to reduction of flow by compression of blood vessels. However, this mechanism differs from BP changes since it does not require metabolic changes in blood plasma (Gladwell & Coote, 2002) and, depending on the volume and population, there may be no significant change in HR (Costa e Silva et al., 2016). We speculate that the reduced number of exercises and, therefore, a low volume of training, did not generate enough increase in the concentration of metabolites to stimulate the metaboreceptor system and to generate a significant hypotensive response.

Gladwell and Coote (2002) compared SS and isometric RT to the autonomic (heart rate variability, HRV) and hemodynamic (SBP and DBP) effects. The authors subjected seven apparently healthy young men to one minute of (passive) SS of the triceps surae muscle and observed that the autonomic effects of SS were similar to those of the isometric exercise (plantar flexion). Accordingly, SS could increase the HR through vagal tone inhibition, albeit without significantly affecting the blood pressure responses. Thus, the authors suggested that these effects resulted from the activation of mechanoreceptors in small muscle fibers. The results of the present study corroborate the data by Gladwell and Coote (2002) because performing stretching exercises concurrent with RT significantly increased the HR after performing the exercises, compared to the resting values. Thus, the HR response after performing stretching exercises noticeably demonstrates an increasing trend, despite using different muscle groups. This response is achieved by a mechanism termed the exercise pressor reflex. Although underreported in humans, this mechanism suggests that stretching generates autonomic changes, especially by increasing the neurotensin (NTS)-triggered sympathetic drive resulting from muscle afferent responses, particularly of type III fibers, which may produce an increased HR (Gladwell & Coote, 2002).

Table 1. Mean and standard deviation of hemodynamic responses following each experimental condition.

Variables	Groups	Pre (M ± SD)	Post (M ± SD)
HR (bpm)	SS + RT	70.0 ± 2.7	93.0 ± 2.3[a]
	RT + SS	71.0 ± 2.0	85.1 ± 2.9
	RT	70.5 ± 2.6	90.0 ± 2.9
PAS (mmHg)	SS + RT	116.3 ± 14.7	124.6 ± 15.2
	RT + SS	123.3 ± 6.9	121.0 ± 5.9
	RT	122.2 ± 11.1	133.7 ± 10.6[b]
RPP (bpm x mmHg)	SS + RT	8,205.1 ± 884.7	11,218.9 ± 1,137.3[c]
	RT + SS	8,755.5 ± 565.9	10,303.3 ± 794.3[d]
	RT	8,619.1 ± 811.1	12,047.1 ± 1,145.5
SpO_2 (O_2)	SS + RT	97.9 ± 0.6	96.0 ± 0.5
	RT + SS	97.9 ± 0.3	90.3 ± 0.8[e]
	RT	98.0 ± 0.6	97.0 ± 0.6

[a]Significant difference between HRpre vs. HRpost (SS+RT vs. SS+RT); [b]Significant difference between PASpost (RT+SS vs. RT); [c]Significant difference between RPPpost vs. RPPpre (SS+RT vs. SS+RT) [d]Significant difference between SS+RT vs. RT+SS in the post period; [e]Significant difference between SS+RT vs. RT+SS in the post period.

McCully (2010) analyzed the SpO_2 following ten minutes of SS of the gastrocnemius, quadriceps, and hamstring muscles in 14 apparently healthy and moderately active subjects using infrared spectroscopy. The author demonstrated that SS could significantly reduce the levels of muscle oxygen saturation of the quadriceps and hamstring muscles. These results occurred due to blood occlusion caused by stretching exercises, a causative of ischemia in some muscles (McCully, 2010). The present study demonstrated that SS of pectoral and quadriceps muscles, when performed concurrently with RT (RT+SS), decreases the muscle oxygen supply in young men. These findings corroborate Costa e Silva et al. (2013), who found an acute reduction in the SpO_2 value after performing different methods of stretching in female athletes who participated in water sports. Such responses may be explained by the viscoelastic deformations of muscles and their capillaries, which explains the measurements recorded when SS was performed at the end of the session because the measurements in the SS+RT protocol were performed using a longer time interval compared to that used after the stretching exercise.

Santos et al. (2014) found that such a combination increased the HR and RPP values after subjecting 19 normotensive men to RT with and without prior use of SS. Therefore, our results are highly relevant, particularly because the literature on this topic is scarce. The inclusion of stretching exercises concurrent with RT noticeably promoted an increased HR and an increased RPP after the end of the session, corroborating the findings of Lima, Farinatti, Rubini, Silva, and Monteiro (2015). Stretching generates lower neural activation, which is associated with lower passive muscular tension (stiffness), rendering the subsequent exercise more intense, which could have caused metabolic compensation marked by an increase in HR and RPP values, according to Fowles, Sale, and MacDougall (2000). SS affects the cardiac overload, as indicated by the increase in HR and RPP values and may also reduce the oxygen supply to the muscle, which is another key finding of the present study. This overload may have been facilitated by the effect of blood occlusion caused by muscle stretching.

The combined use of SS with RT was able to significantly change the intragroup cardiovascular responses, increasing the HR and RPP and decreasing the SpO_2 values, depending on the sample. However, the hemodynamic values observed in the intergroup comparisons were lower when stretching exercises were performed both before and after completing RT, although no significant differences occurred from a cardiovascular safety perspective. Thus, stretching exercises should be included in combination with resistance exercises when the goal is to preserve the cardiovascular system.

Finally, some limitations may have affected the results of the present research study. Accordingly, even with proper care, the failure to measure variables, including the hormone levels, autonomic responses, body and room temperature, sleep time, and nutrition may affect, to some extent, the analysis of these results. New studies examining various stretching methods and different intensities and sample groups should be performed to extrapolate our findings.

Conclusion

In conclusion, it is possible to say that in the intragroup comparison, SS and RT significantly alter the cardiovascular responses by increasing HR and RPP and decreasing SpO2. However, in the intergriup comparisons, the values were lower when the stretching exercises were performed before and after RT, although no significant differences were found from the point of view of cardiovascular safety.

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