Journal of Physical Education and Sport ® (JPES), Vol. 21 (4), Art 208, pp. 1643 - 1649, June 2021
online ISSN: 2247 - 806X; p-ISSN: 2247 – 8051; ISSN - L = 2247 - 8051 © JPES

Original Article

Effect of load intensity and cuff pressure during blood flow restriction performed to failure on training volume and myoelectric activity

EWERTTON S. BEZERRA[1], JOÃO PEDRO NUNES[2], LUCAS B. R. ORSSATTO[3], RAPHAEL L. SAKUGAWA[4], MATEUS ROSSATO[5], ALEX S. RIBEIRO[6]
[1,5] Human Performance Laboratory. Federal University of Amazonas, BRAZIL.
[2] Metabolism, Nutrition, and Exercise Laboratory. Londrina State University, BRAZIL.
[3] School of Exercise and Nutrition Sciences. Queensland University of Technology, AUSTRALIA.
[4] Biomechanics Laboratory. Federal University of Santa Catarina, BRAZIL.
[6] Center for Research in Health Sciences. University of Northern Paraná, BRAZIL.

Published online: June 30, 2021
(Accepted for publication June 15, 2021)
DOI:10.7752/jpes.2021.04208

Abstract
The aim of the present study was to investigate the influence of intensity of load and cuff pressure on training volume and myoelectric activation during the knee extension exercise executed with and without blood flow restriction (BFR) to failure. Ten young men (22 ± 2 y), with at least six months of training experience, visited the laboratory on eight non-consecutive days with intervals of at least 48 hours between sessions. In the first two visits, one-repetition maximum (1RM) test and retest were performed in the unilateral knee extension exercise. In the subsequent six visits, the subjects performed resistance training sessions (4 sets to concentric failure) at different load intensities (30, or 40% of 1RM) and BFR pressures (0, 100, or 150mmHg). The restriction cuff was of 18-cm width and was positioned on the superior 1/3 of the thigh. Measures of training volume, and myoelectric activity from the vastus lateralis and vastus medialis via surface electromyographic, were recorded. During experimental sessions, it was observed that the use of BFR significantly reduced the training volume, independently of the load used. Less repetitions were performed with a restriction pressure of 150mmHg (47 ± 10) compared to 0mmHg (61 ± 15) and 100mmHg (59 ± 17), and with 30%1RM (50 ± 14) compared to 40%1RM (61 ± 15). For surface electromyography measures, no significant differences were observed between the conditions (P>0.05). In conclusion, the application of BFR to low-load knee extension exercise to failure led to lower training volume but did not influence myoelectric activity.
Keywords: **KAATSU, vascular restriction, resistance training, effort, fatigue**

Introduction

Resistance training (RT) is can induce several benefits for health, well-being, performance, and aesthetics (ACSM 2009). The proper manipulation of training variables should be considered to maximize RT-induced adaptations (ACSM 2009). Traditionally, the American College of Sports Medicine recommends performing resistance exercises with an intensity of load above 70% of one-repetition maximum (1RM) to provide sufficient stimulus to improve muscle strength and size (ACSM 2009). However, the use of relatively low loads has been recently suggested as an alternative strategy to traditional RT for inducing positive adaptations in these outcomes (Schoenfeld et al. 2017). Moreover, for subjects who do not like or cannot train with high loads, the application of blood flow restriction (BFR) during RT with low loads is an option (Loenneke et al. 2012a; Pearson & Hussain 2015; Jessee et al. 2018a; Patterson et al. 2019). Low-load BFR-RT enables subjects to improve strength and muscle mass similarly to traditional RT (Loenneke et al. 2012a; Pearson & Hussain 2015; Jessee et al. 2018a; Patterson et al. 2019), and more efficiently than low-load RT without BFR (Loenneke et al. 2012b, 2012a; Pearson & Hussain 2015; Jessee et al. 2018b, 2018a; Patterson et al. 2019).

The efficiency of BFR-RT seems to be related to its capacity to create a more hypoxic and metabolic environment (Pearson & Hussain 2015; Jessee et al. 2018b), increasing myoelectric activation and swelling, factors that have been proposed to stimulate greater muscular adaptations (Wilson et al. 2013). Some studies indicate that BFR-RT enhances muscular activation (Yasuda et al. 2006; Wilson et al. 2013; Centner & Lauber 2020). However, these findings are not consistent (Patterson et al. 2019), and most studies that observed some advantage had explored BFR-RT with a controlled number of repetitions and sets being not performed until failure. It is expected that performing the RT to failure may equate the effort between BFR and non-BFR conditions (Dankel et al. 2018), but it remains to be further explored.

The responses to BFR-RT are dependent on the relative load (%1RM) and cuff pressure used (Loenneke et al. 2012a; Jessee et al. 2018b; Patterson et al. 2019). For instance, in fixed-repetitions protocols, higher muscular activation was observed with increased cuff pressure (Yasuda et al. 2008), however, in failure

Corresponding Author: JOÃO PEDRO NUNES, E-mail: joaonunes.jpn@hotmail.com

sets, increased load intensity or cuff pressure resulted in lower repetitions (Jessee et al. 2018a). It is needed to investigate how different load intensities and cuff pressures interact with each other and influence repetitions volume and muscular activation following BFR-RT to failure. In addition, given the relation between volume-load (repetitions x sets x load) and muscular gains (Schoenfeld & Grgic 2018; Longo et al. 2020), it is needed to be explored which magnitude of low-load intensity and cuff pressure may propitiate the greater volume to a common degree of muscular activation.

In this sense, the purpose of this study was to investigate the interaction between load and cuff pressure on training volume and myoelectric activation during the knee extension exercise. It was hypothesized that the application of BFR would lead to lower volume with similar sEMG activity.

Materials and methods

Experimental design

Participants visited the laboratory on eight non-consecutive days with at least 48 hours between sessions. In the first two visits, the 1RM test and retest were performed respectively in the knee extension exercise. In the subsequent six visits, participants performed an RT session with different loads (30 or 40% of 1RM), and with different restriction pressures (100 or 150 mmHg), or a control session (non-BFR; "sham occlusion" using the tourniquet with 0mmHg). The order of the six sessions was randomized for each participant (Figure 1).

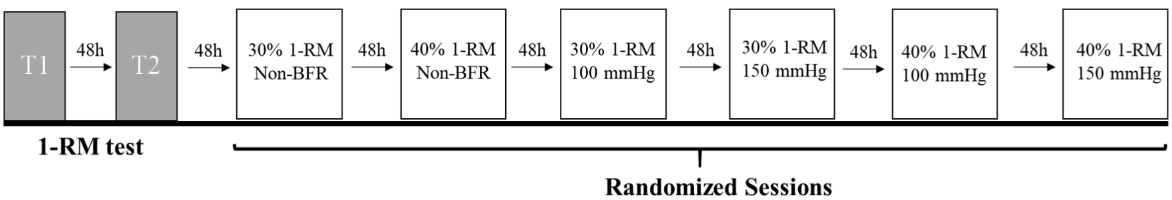


Figure 1. Experimental design. T1=1RM test; T2=1RM retest; BFR=blood flow restriction (0mmHg); RM=Repetition maximum.

Participants

Ten recreationally trained male subjects (22.1 ± 2.0 years, 1.77 ± 0.06 m, 84.7 ± 13.6 kg) were recruited for convenience and included in this study if they met the following inclusion criteria: age ranging between 18 and 30 years and at least 6 months of RT experience with a frequency of 3 times per week. Participants were excluded from the study if they had any musculoskeletal limitations, and/or hemodynamic alterations that would be contraindicated to perform the experimental protocol. The participants were instructed to refrain from any additional RT throughout the experiment and were advised to maintain their normal nutritional regimen and not to start taking any supplements or ergogenic resources. All subjects gave their written informed consent, and the study was approved by the ethics committee of the university (protocol number: 32025314.2.0000.5020) in agreement with the Declaration of Helsinki.

1RM testing

The 1RM test was performed on the subjects' preferred leg in the unilateral knee extension exercise (Rotech equipment. Goiás, Brazil) according to recommended proceedings (Haff & Triplett 2016). Briefly, participants performed a warm-up with light resistance (~50% of estimated 1RM) for 5 to 10 repetitions. The resistance was then increased and the participants performed 2 to 3 repetitions. From this point forward, the participants performed 1 repetition with each progressively increased load until the 1RM was achieved. The goal was to complete a maximal lift within five attempts. Two minutes of rest was provided between each set. To ensure that the true 1RM was reached, subjects were encouraged to perform two repetitions. Thus, if a repetition could not be performed, the weight was reduced for the next trial, and if two repetitions were performed, the weight was increased. The 1RM value was the maximum load that the subject was able to lift during a single knee extension (47 ± 7 kg).

Exercise sessions

In all training sessions, four sets were performed to concentric momentary failure, with a 1-min interval between sets. Strong verbal encouragement was given during each set for all subjects, especially during the final repetitions, ensuring that concentric failure was achieved. The number of repetitions and sEMG values were registered during each set. Training volume variables were considered as the total number of repetitions (Σ all repetitions of all sets; no.) and volume-load (repetitions x sets x load; kg) (Nunes et al. 2021). The restriction pressure value was chosen based on results from Loenneke et al. (2012c). An 18 cm wide cuff was positioned on the superior 1/3 of the thigh. The device was adapted from blood pressure equipment, which consists of an inflatable rubber bag of laminar shape, which is surrounded by an inelastic fabric cover (cuff) and connected by a rubber tube to a pressure gauge and another tube, which contains an operator-controlled valve.

Myoelectric activity

Surface electromyographic (sEMG) data were recorded for the Vastus Lateralis (VL) and Vastus Medialis (VM) during all protocol conditions (Criswell & Cram 2011). For analysis, three central repetitions of each set were considered (Wright et al. 1999). Before EMG acquisition, appropriate preparation of the skin was carried out to remove body hair, oils, and flaky skin layers and, consequently, reduce the impedance in the electrode-gel-skin interface. Preparation included shaving hair, abrading, and cleaning the skin surface with alcohol. All procedures for EMG data collection were according to the Surface Electromyography for the Non-Invasive Assessment of Muscles guidelines (Hermens et al. 2000). For the acquisition of sEMG, surface signals were collected using a wireless NoraxonMyoSystem® 1400A with 8 input channels. The sEMG signal was filtered with a bandpass between 20 and 450Hz. The sampling rate of the signal was 1000 Hz. To guarantee that electrodes remained at the same site in all testing sessions, the position was marked with a dermatologic pencil. The Root Mean Square (RMS) values of VL and VM were calculated for 3 central contractions of each set. For analysis, the RMS sum (VL + VM) was used to represent muscle activation of the quadriceps. The sEMG values were determined by an average of the sEMG values of three central repetitions of each set (Farias et al. 2017). Normalization was carried out using the highest peak sEMG value (Wright et al. 1999; Farias et al. 2017). All data processing was carried out in MATLAB® (Natick, MA, USA).

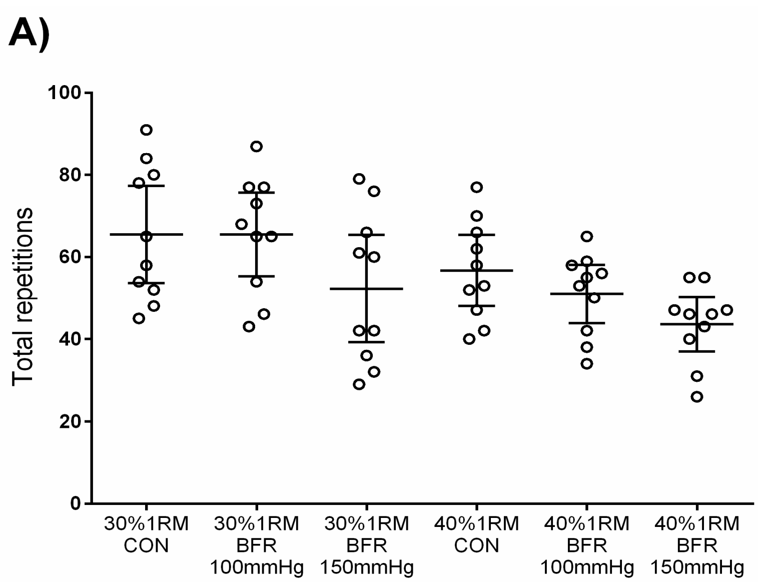
Statistical analyses

Quantile-quantile plots confirmed the normality of data, and Levene's test was used to confirm the between-groups homogeneity of variance. Two-way ANOVA (2 loads vs. 3 BFR conditions) was performed to compare outcomes. Bonferroni post-hoc analysis was conducted when interactions were identified. Statistical significance was set at $P < 0.05$. The data were stored and analyzed using IBM SPSS v.24 (IBM Corp., Armonk, USA).

Results

Training volume

Post-hoc comparisons between different intensities (30 and 40% of 1RM) for each restriction pressure (0, 100 and 150 mmHg) are presented in Figure 2. For total repetitions, main effects of load ($F = 7{,}556$; $P = 0.008$; $\eta_p^2 = 0.123$) and restriction pressure ($F = 5{,}767$; $P = 0.005$; $\eta_p^2 = 0.176$) were observed, where less repetitions were performed at 40% of 1RM (50 ± 14 repetitions) compared to 30% of 1RM (61 ± 15 repetitions), as well as at 150mmHg (47 ± 10 repetitions) compared to 0mmHg (61 ± 15 repetitions) and 100mmHg (59 ± 17 repetitions), as displayed in Figure 2A. For volume-load, no significant effects of load ($F = 0{,}917$; $P = 0.343$; $\eta_p^2 = 0.017$), restriction pressure ($F = 2{,}315$; $P = 0.108$; $\eta_p^2 = 0.079$), and load*pressure interaction were observed ($F = 2{,}661$; $P = 0.079$; $\eta_p^2 = 0.090$; Figure 2B).



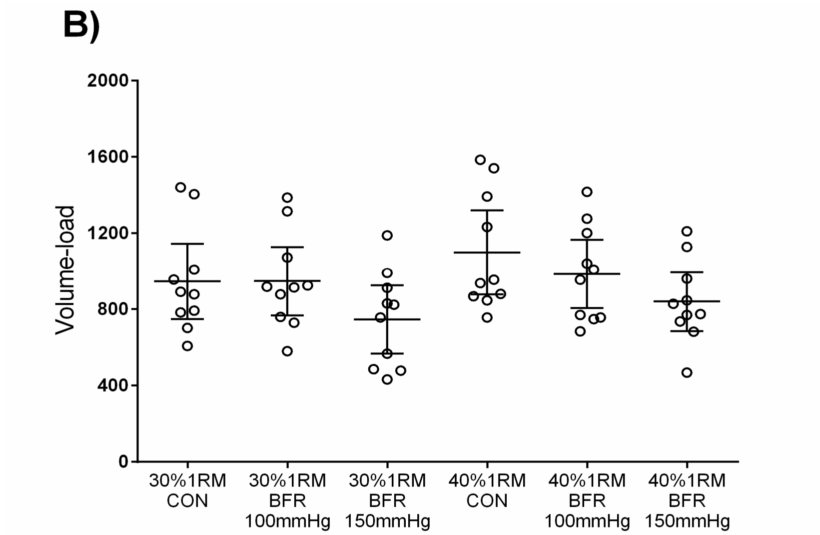


Figure 2. Repetitions (no.) and volume-load (kg) according to loads and cuff pressures during knee extension exercise with and without blood flow restriction (n = 10). Data are presented as mean and 95% confidence intervals.

Myoelectric activity

There were no observed main effects of load (F = 3,411; P = 0.070; η_p^2 = 0.059) or restriction pressure (F = 1,372; P = 0.262; η_p^2 = 0.048) for sEMG RMS, although a significant load*pressure interaction was found (F = 5,543; P = 0.006; η_p^2 = 0.170). Post-hoc comparisons are represented in Figure 3.

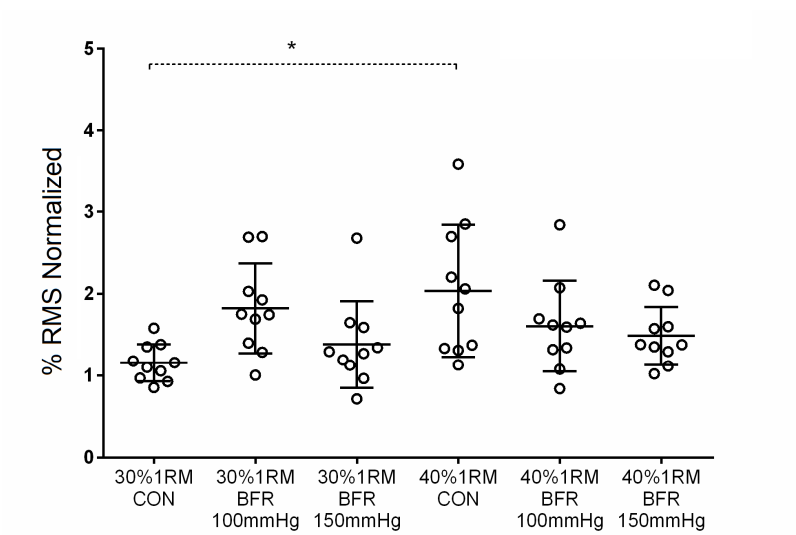


*Figure 3. Myoelectric activation (vastus lateralis and vastus medialis) according to loads and cuff pressures during knee extension exercise with and without blood flow restriction (n = 10). Data are presented as mean and 95% confidence intervals.*P < 0.05 difference between indicated conditions*

Discussion

The main findings of the current study were that the application of BFR to the knee extension exercise with low load (30% and 40% of 1RM) resulted in lower repetitions, but only when a pressure of 150mmHg was used. No significant differences were observed between conditions for sEMG concerning the use of BFR. The results confirmed our initial hypothesis for training volume and sEMG.

Regarding the training volume, an interesting finding was that the application of BFR with restriction pressure of 100mmHg was not sufficient to reduce the number of repetitions, whereas the application of 150mmHg did reduce it. This may be related to the momentary muscular fatigue induced by the application of BFR, that is, only the pressure of 150mmHg was sufficient to occlude the venous return in a manner that induced fatigue to the point of reducing the training volume significantly. The 100mmHg restriction pressure used most likely allowed for some washout of metabolites (Wernbom et al. 2009; Jessee et al. 2018b), and therefore, neither the training volume nor the muscular activation was different from the non-BFR condition. Although we used absolute occlusion pressures (100 and 150mmHg) and not the relativized ones (% of arterial occlusion pressure), our results present similarities to those presented by Bell et al. (2018). The authors showed a significant reduction in training volume only when a relative arterial occlusion pressure of 80% (but not 40%) was applied by the cuff, indicating that the reduction in training volume is observed only when higher restrictions are used.

For surface electromyography results, there was a significant difference only between control conditions (non-BFR, 30% vs. 40% of 1RM), in which higher sEMG-RMS was observed for 40%1RM. This result was expected given the relationship between relative load and sEMG-RMS (Schoenfeld et al. 2014). Different from our findings, several other studies observed increases in muscular activation with higher cuff pressures (Yasuda et al. 2008; Fatela et al. 2016; Centner & Lauber 2020). However, the majority of these studies controlled the number of repetitions to be performed (such as the traditional 4 x 30-15-15-15-reps protocol (Patterson et al. 2019)), and the sets were not performed until failure. The lack of difference between the conditions in the present study may be related to the fact that all sets were performed until failure. Indeed, recent studies have shown that application of BFR induces higher accumulation of metabolites and greater fatigue compared to the control conditions, mainly when exercise is not performed until failure (Yasuda et al. 2008; Loenneke et al. 2012b; Jessee et al. 2018b).

The greater accumulation of metabolites offered by the BFR seems to induce earlier neuromuscular fatigue through the stimulation of group III and IV afferent fibers (Pearson & Hussain 2015; Jessee et al. 2018b), resulting in the recruitment of higher threshold motor units with the same training volume (Pearson & Hussain 2015; Jessee et al. 2018b). That is, the potential importance of applying BFR when exercise is not performed to failure is to increase fiber recruitment and muscular activation. However, when performed to failure, small increases in muscular activation with small reductions in training volume are observed, equalizing the stimulus offered (Dankel et al. 2017).

Improvements in muscle morphofunction seem to be related to patterns of motor unit activation during the exercise. Some authors report that greater hypertrophy can be obtained with higher recruitment of motor units (Fisher et al. 2013), as well as greater strength gains (Schoenfeld et al. 2017). Others state that muscle hypertrophy cannot be predicted by acute surface electromyography (sEMG) measures, since similar gains in hypertrophy have been observed with RT with low and high loads (Schoenfeld et al. 2017), whereas higher sEMG-RMS have been observed in resistance exercises with high loads (Schoenfeld et al. 2014). However, since low load exercises generate lower levels of muscular activation, this may explain why this type of protocol needs to be performed at higher training volumes to promote muscle growth similar to high load training. Although further studies on this topic are needed to elucidate these divergences, the greater activation with relatively high training volume may be the acute stimulus that induces potentially greater muscular adaptations. Considering the balance between muscular activation levels and training volume, potential increases in muscle size may be equal after a chronic intervention using the protocols tested evaluated in the present study (Yasuda et al. 2006, 2014; Wernbom et al. 2009; Fukuda et al. 2013; Wilson et al. 2013; Dankel et al. 2018). Jessee et al. (2018a) recently compared the effects of high- and low-load RT to failure with and without BFR and observed similar increases in knee extensor muscle thickness, attesting that increases in muscle size did not depend on load, and were not affected by the differences in restriction pressures.

The present study some limitations to be addressed. First, although we used a crossover design, which reinforces the findings presented, as subjects are their own controls, the sample size can be considered small, underpowering the analyses. Another point is that we did not measure physiological variables related to fatigue, such as lactate production, or stress hormones such as cortisol, which are likely to influence the perceptual response to exercise (Yasuda et al. 2014). Finally, we used fixed cuff pressures of 100 and 150mmHg while other authors suggest that the restriction pressure should be individualized (Jessee et al. 2018b). It is worth mentioning that our results are restricted to the included population and training protocol and extrapolation to other conditions should be performed with caution.

Conclusions

Our results suggest that the application of BFR to low-load knee extension exercise performed until failure leads to lower training volume only when using 150mmHg, but does not influence the myoelectric activity in young men. Strength and conditioning coaches and practitioners may consider the use of low-load exercises as an alternative to the currently recommended traditional high-load protocols. When adopting low-load BFR-RT to failure, a balance between small non-significant increases in muscular activation and reductions in volume-load tends to be observed in a variety of load intensities and cuff pressures. This provides a more flexible prescription without a restricted need for training volume and cuff pressure monitoring.

Conflict of interests: The authors declare that they have no conflict of interest regarding the publication of this paper. **Funding:** None. **Acknowledgments:** The authors thank all subjects for their engagement in the study.

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