AUTHOR QUERIES

DATE 6/13/2016
JOB NAME JSCR

ARTICLE JSCR-08-5615
QUERIES FOR AUTHORS Martín-Hernández et al

THIS QUERY FORM MUST BE RETURNED WITH ALL PROOFS FOR CORRECTIONS

Please confirm the given names (pink) and surnames (blue) of authors have been identified correctly.

AU1) Please note that there is discrepancy between the pdf and the original manuscript in the name of all the author "Juan A. Herrero." The author manuscript has been followed. Please check and change accordingly. Also please provide middle initial(s) for the authors "Juan Martín-Hernández," "Jorge Ruiz-Aguado," "Per Aagaard," "Carlos Cristi-Montero," and "Héctor Menéndez."

AU2) Please note that affiliation should be anglicized as per style. Please check. Please check the edits made in affiliation section and also provide the department/unit (if any) for the affiliations "2, 5 and 6."

AU3) Please note that BFRT has been spelled out as "blood flow–restricted training" in the abstract and as "blood flow restriction training" in the text. Please check and make consistent.

AU4) Please note that "HIT" has been spelled as "high-intensity training" in the abstract and as "high-intensity resistance training" in the text. Please check and make consistent.

AU5) Please provide the age ranges for all subjects mentioned in the Subjects section if you have not already. If any subjects were <18 years of age, please confirm that parental consent was obtained. Please also confirm, if you have not already, that informed consent documents were signed for all subjects.

AU6) Please note that as per the journal style, table and figure placements are not allowed in the "Discussion" section and hence have been introduced in the "Pain" section. Please check and correct if necessary.

Adaptation of Perceptual Responses to Low-Load Blood Flow Restriction Training

AU1 Juan Martín-Hernández,[1] Jorge Ruiz-Aguado,[1] Juan A. Herrero,[1,2] Jeremy P. Loenneke,[3] Per Aagaard,[4] Carlos Cristi-Montero,[5,6] Héctor Menéndez,[2] and Pedro J. Marín[1]

[1]*Department of Health Sciences, Faculty of Health Sciences, Miguel de Cervantes European University, Valladolid, Spain;* [2]*Research Centre on Physical Disability, ASPAYM Castilla y León Association, Valladolid, Spain;* [3]*Department of Health, Exercise Science, and Recreation Management, The University of Mississippi, Oxford, Mississippi;* [4]*Muscle Physiology and Biomechanics Research Unit, Institute of Sports Science and Clinical Biomechanics, University of Southern Denmark, Odense, Denmark;* [5]*Grupo IRyS, Escuela de Educación Física, Pontificia Universidad Católica de Valparaíso, Valparaíso, Chile; and*
AU2 [6]*Universidad Autónoma de Chile, Santiago, Chile*

Abstract

Martín-Hernández, J, Ruiz-Aguado, J, Herrero, JA, Loenneke, JP, Aagaard, P, Cristi-Montero, C, Menéndez, H, and Marín, PJ. Adaptation of perceptual responses to low-load blood flow restriction training. *J Strength Cond Res* XX(X): 000–000, 2016—The purpose of this study was to determine the adaptive response of ratings of perceived exertion (RPE) and pain over 6 consecutive training sessions. Thirty subjects were assigned to
AU3 either a blood flow–restricted training (BFRT) group or a high-
AU4 intensity training (HIT) group. Blood flow–restricted training group performed 4 sets (30 + 15 + 15 + 15, respectively) of unilateral leg extension at an intensity of 20% one repetition maximum (1RM) while a restrictive cuff was applied to the most proximal part of the leg. The HIT group performed 3 sets of 8 repetitions with 85% 1RM. Ratings of perceived exertion and pain were assessed immediately after each exercise set along the 6 training sessions and were then averaged to obtain the overall RPE and pain per session. Statistical analyses showed significant main effects for group ($p \le 0.05$) and time ($p < 0.001$). Ratings of perceived exertion values dropped from session 1 to session 6 in both BFRT (8.12 ± 1.3 to 5.7 ± 1.1, $p < 0.001$) and HIT (8.5 ± 1.2 to 6.40 ± 1.2, $p < 0.001$). Similar results were observed regarding pain ratings (BFRT: 8.12 ± 1.3 to 5.90 ± 1.55, $p < 0.001$; HIT: 6.22 ± 1.7 to 5.14 ± 1.42, $p < 0.01$). Our results indicate that RPE was higher after HIT, whereas differences did not reach significance regarding pain. These perceptual responses were attenuated over time, and the time course of this adaptive response was similar between BFRT and HIT. In summary, BFRT induces a marked perceptual response to training, comparable with that observed with HIT. However, this response becomes attenuated with continuous practice, leading to moderate values of RPE and pain. Perceptual responses may not limit the application of BFRT to highly motivated individuals.

Key Words RPE, pain, hypertrophy, KAATSU, CR10

Address correspondence to Juan Martín-Hernández, jmartinh@uemc.es.

00(00)/1–8

Journal of Strength and Conditioning Research

Introduction

Conventional resistance exercise with high mechanical loading is the most frequently used training method to stimulate protein synthesis and muscle hypertrophy (44). In this sense, it is recommended to lift weights of at least 70% one repetition maximum (1RM) to optimize training adaptations (3). However, low-load, high-volume training recently was also shown to acutely stimulate muscle protein synthesis (4) and to ultimately promote muscle growth (35), especially when training is carried out to volitional fatigue (28). Blood flow restriction training (BFRT) has emerged as an effective method to promote muscular development (22,42). Blood flow restriction training involves moderate- to high-volume, low-load resistance exercise combined with a moderate reduction of arterial inflow and a blockage of venous outflow of the working muscles (19).

There is growing evidence that low-intensity exercises may elicit marked increases in muscle growth when combined with the moderate BFRT stimulus. Increments in muscle mass may be reached by combining the restrictive stimulus not only with low-load resistance training (22) but also with many other low-intensity tasks, such as walking (1) or elastic band resistance training (36). Indeed, these increments in muscle mass after low-load resistance training in combination with blood flow restriction have shown to be, in many cases, equal to those observed after traditional high-load resistance training in physically active males (15,24).

These characteristics make BFRT an enticing method to preserve and promote muscle mass, especially in populations advised not to perform high-load resistance training; for instance, elderly or rehabilitating patients (17) including some conditions of severe muscle atrophy because of disease (12). Blood flow restriction training walking (2) and BFRT resistance training (34) have previously been observed to result in skeletal muscle hypertrophy in the aged population. Of interest, the restrictive stimulus per se may also play a role in maintaining muscle mass during an unloading period (33), although neuromuscular function might only be partially maintained (6).

Blood flow restriction training seems to be an effective and safe alternative for frail populations taking into account that the low mechanical load seems to induce no measurable muscle damage. As recently reviewed by Loenneke et al. (20), BFRT produces no prolonged decrements in muscle function (37), no measurable prolonged muscle swelling (37,46), no elevations in blood markers of muscle damage (11,32), no signs of altered nerve or vascular function, no changes in selected markers of coagulation and inflammation (5), and no changes in markers of arterial stiffness (47) and muscle soreness levels similar to submaximal load controls (37,46). However, training tolerance may not only be determined by physiological variables. Strength and conditioning professionals should be aware of how training programs are perceived and psychologically tolerated by practitioners. Subjective perceptions influence participant's attitude toward training, and ultimately affect motivation and adherence, both of which should be as important as the safety or effectiveness of training protocols (39). Therefore, to represent a true exercise alternative–especially in special populations–BFRT should also be psychologically well tolerated.

Apart from cardiovascular safeness, unpleasant feelings during BFRT could be considered among the main issues of this training method, as unpleasant exercise is less likely to be maintained in the long term (7). In this sense, the restriction of blood flow has been shown to increase the perceived exertion for a given exercise as compared with work-matched nonrestricted (i.e., free flow) control exercise (45). Indeed, a single session of BFRT in novel practitioners has been associated with high (29) and maximal ratings of perceived exertion (RPE) (45). The level of perceived exertion to BFRT may even rise over that of traditional high-intensity resistance training when using high-occlusion pressures with a wide cuff (40). Other perceptions, such as muscle burning or aching have also been described acutely during BFRT (41). In the context of BFRT, afferent nociceptors may be stimulated by local hypoxia, leading to ischemic pain. Consequently, several studies have also found pain ratings to range from moderate (18) to maximal (45) during a single session of BFRT.

Blood flow restriction training seems to be an enticing alternative for frail population but, at once, all the aforementioned perceptual responses have led to the suggestion that BFRT may be limited to highly motivated individuals only (45). This suggestion should be made with care, as it could prevent strength and conditioning professionals from prescribing this training method despite its potential benefits. Perceptual responses to BFRT have been previously reported; however, all studies have limited their data collection to a single training session in subjects who were not familiarized to BFRT. To the best of our knowledge, there is only 1 study that has longitudinally assessed subjects' perceptions (41). Unfortunately, the results are difficult to interpret because occlusion pressure was gradually increased week to week throughout most of the intervention period. Therefore, the purpose of the present study was twofold: (a) to determine whether ratings of perceived effort and pain are altered after 6 consecutive sessions of BFRT; (b) to compare whether these perceptual responses are similar to those observed after traditional high-intensity resistance training (HIT).

Methods

Experimental Approach to the Problem

Subjects attended the laboratory twice a week over 5 weeks. They were familiarized with testing and training procedures during the first 2 weeks (4 familiarization sessions), and data were collected over the 3 remaining weeks. Familiarization sessions began with 1RM testing until the values flattened off. Values were considered flattened when a coefficient of variation lower than 5% was registered in 2 consecutive sessions. Participants were then instructed on how to rate and distinguish RPE and pain, as described in detail below. Finally, they were described BFRT and HIT protocols in detail; however, no practice with BFRT or HIT was allowed to avoid a possible accommodation of subjective perceptions before data collection. After the familiarization period, the sample was randomized into 2 different groups: a low-intensity, blood flow–restricted training group (BFRT, $n = 14$) and a traditional high intensity training group (HIT, $n = 14$). From this point, subjects visited the laboratory twice a week to complete 6 training sessions. Consecutive training sessions were separated by at least 48 hours. Ratings of perceived exertion and pain were assessed immediately after each exercise set across the 6 training sessions.

Subjects

Thirty recreationally active male university students (BFRT: AU5 $n = 15$; mean ± *SD*: age 21 ± 1 years [range: 19–25 years]; height 178.3 ± 5.8 cm; weight 73.7 ± 8.7 kg; and HIT: $n = 15$; mean ± *SD*: age 21 ± 1 years [range: 19–24 years]; height 178.7 ± 7.3 cm; weight 73.3 ± 8.8 kg) volunteered for the study. They all reported to perform physical activity at least 3 $d \cdot wk^{-1}$ but were not currently engaged in a structured aerobic or resistance training program. Subjects were excluded from the study if they had a body mass index greater than 30 $kg \cdot m^{-2}$ or self-reported any cardiovascular disease or musculoskeletal problems that may hinder their ability to perform resistance exercise. Subjects also were told to refrain from use of analgesics, anti-inflammatories or any other substances that may influence their RPE and pain. Before data collection, subjects were informed about the risks and benefits of the study, and all subjects gave their written informed consent. The research project was conducted in accordance with the ethical standards of the Declaration of Helsinki and received the ethical approval by the University Review Board for use of Human Subjects.

Procedures

Maximal isotonic unilateral leg extension strength was determined using a monoarticular leg extension exercise, performed in a leg extension machine (SuperGym, SG8019 Leg Ext/Hamstring Combo; Qingdao Impulse Group Co., Ltd., Shandong, China). The dominant leg was used for testing and training in both groups. The 1RM was considered as the maximum weight in kilograms that could be lifted only once in this particular piece of equipment through the full range of motion. After a standardized warm-up, subjects lifted a weight equivalent to an estimated 50% 1RM and performed 8 repetitions. After resting for 3 minutes, they performed 5 repetitions with a load estimated at 75% 1RM. These initial bouts served as a specific warm-up. Finally, the weight was adjusted to the estimated 1RM and subjects were told to perform 1 set to failure throughout the full range of motion. If they managed to perform more than 1 repetition, the weight was readjusted and they went for a second attempt after a 5-minute rest period. On average, 3 trials were required to complete the 1RM test. Subjects were instructed to keep their arms crossed over the chest to avoid any synergistic movement of the upper body during each attempt.

All subjects underwent 6 training sessions. Blood flow restriction training and HIT training protocols were designed according to the general recommendations by Loenneke et al. (22) and ACSM (3), respectively. Training volume in the BFRT group was adjusted to 75 repetitions per session and training intensity was set to 20% 1RM of subjects' previously measured unilateral concentric 1RM. Training volume was organized in 4 sets (30 + 15 + 15 + 15, respectively) with an interset rest interval of 60 seconds. Restrictive stimulus was given by means of a compressive pneumatic cuff that was applied to the most proximal end of the subjects' dominant leg (RiesterKomprimeter; Riester, Jungingen, Germany). The cuff was 140 mm wide and 940 mm long. Before each training session, the cuff was progressively inflated as described by Fahs et al. (8) until a pressure of 110 mm Hg was reached (25). After completing the last repetition, subjects were asked to rate their RPE and PAIN of the last bout (more details given below). Immediately after exercise (end of the fourth set), the cuff was deflated and removed.

Regarding the HIT group, exercise intensity was set at an 85% of the previously measured unilateral concentric 1RM. Training volume was adjusted to the standard of 3 sets of 8 repetitions (or until volitional failure) with 60 seconds interset rest intervals (3). Eight repetitions per set exceeds the general acceptance of a maximum of 6 repetitions for 85% 1RM; however, this recommendation is based upon bilateral small–muscle groups exercises and, based on bilateral deficit, this may not be valid to unilateral large–muscle groups exercises (30,38). Subjects in both groups were told to lift the load at a controlled cadence of 2s-2s for the concentric and eccentric phase, respectively (9); however, a metronome was not used during training (36). Exercise was carried out in the same leg extension machine used for 1RM assessment.

Ratings of perceived exertion and pain (PAIN) were assessed immediately after each exercise set along the 6 training sessions and were then averaged to obtain the overall RPE and PAIN per session. Both variables were assessed through modified Borg exertion (CR-10) and pain (CR-10+) visual analog scales with colors and emoticons associated to each level of exertion and pain, respectively. These scales have been shown to be valid and reliable in exercise and pain studies (13) and have already been used to quantify RPE and PAIN in previous BFRT research (41).

While resting on the leg extension machine, subjects were given a CR-10 sliding metric scale with emoticons and colors associated to the perceived exertion and pain. Only the emoticons and colors were visible for the subjects, but a continuum from 0 to 10 in the opposite side of the rule was blinded. Subjects were instructed in how to distinguish and value the effort and pain during exercise as previously described by Hollander et al. (14) and Loenneke et al. (21).

For RPE, subjects were told "we want you to rate your perceived exertion, i.e., how heavy and strenuous the exercise feels to you. The perception of exertion depends mainly on the strain and fatigue in your muscles. We want you to use this scale from no exertion at all to maximal exertion; any questions?" (18,21).

PAIN was described to the subjects as a sensation of muscle burning, typically associated to local hypoxia. For PAIN assessment, subjects were directed to rate their pain in relation to their worst pain experience. Subjects were asked "What is your worst experience of pain? Maximum pain should be your main point of reference, and should be associated with the maximum mark in the scale (i.e., 10); however, this may not be the maximum pain associated with this exercise. You could feel a level of pain that is still stronger than 10. Should this be the case, you could verbally rate 11 or 12. If the pain is much stronger, e.g., 1.5 times your worst ever pain you will say 15; any questions?" (18)

During the familiarization sessions, all subjects confirmed that they understood the instructions on how to rate their exertion and pain.

Statistical Analyses

All analyses were performed using statistical software (IBM SPSS 20 for MacOS; IBM, Chicago, IL, USA) with variability presented as *SD*. The normality of the data was checked and subsequently confirmed with the Shapiro-Wilk test. A 2-way repeated measures analysis of variance (2-way RM-ANOVA) was used to compare the data series of RPE

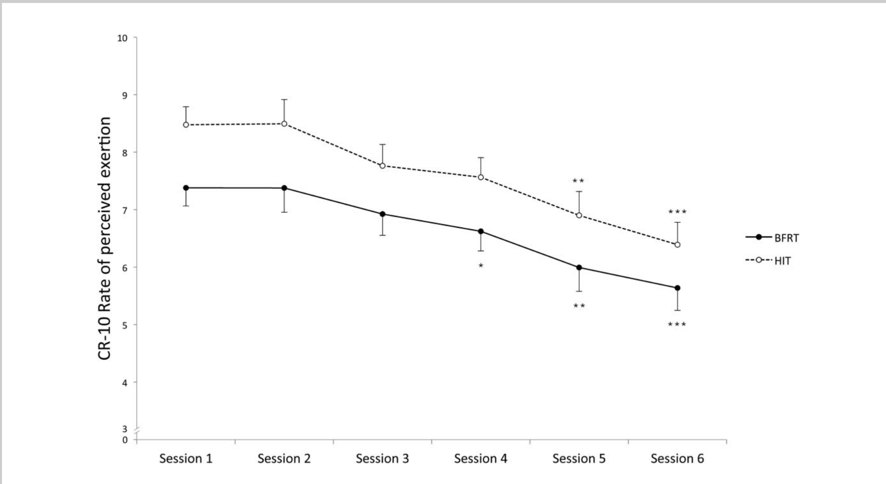

Figure 1. Ratings of perceived exertion (RPE) values after each session of blood flow restriction training (BFRT) and high-intensity training (HIT). Each session RPE is expressed as the average RPE of all sets. Values are mean ± *SE*. *, **, *** significantly different from session 1 ($p \leq 0.05$, $p < 0.01$, $p < 0.001$, respectively).

and PAIN of both groups (group) over the 6 training sessions (time). Two-way RM-ANOVA was followed by a Fisher's least squares differences post hoc analysis when significant main effects were achieved. The level of significance was fixed at an alpha of ≤0.05. Partial eta squared (η^2) was used as an estimate of the effect size of main interactions. Partial eta squared indicates the percentage of variance in each of the interactions and can be interpreted by Cohen's rule of thumb on magnitude of size effects: $\eta^2 < 0.01$ = null effect; $0.01 < \eta^2 < 0.06$ = small effect; $0.06 < \eta^2 < 0.14$ = medium effect; $\eta^2 > 0.14$ = large effect.

Results

Two subjects (1 BFRT, 1 HIT) dropped out for personal reasons unrelated to the investigation. They completed 4 and 5 training sessions, respectively. Consequently, data obtained for the remaining 14 subjects were used for data analysis in each group.

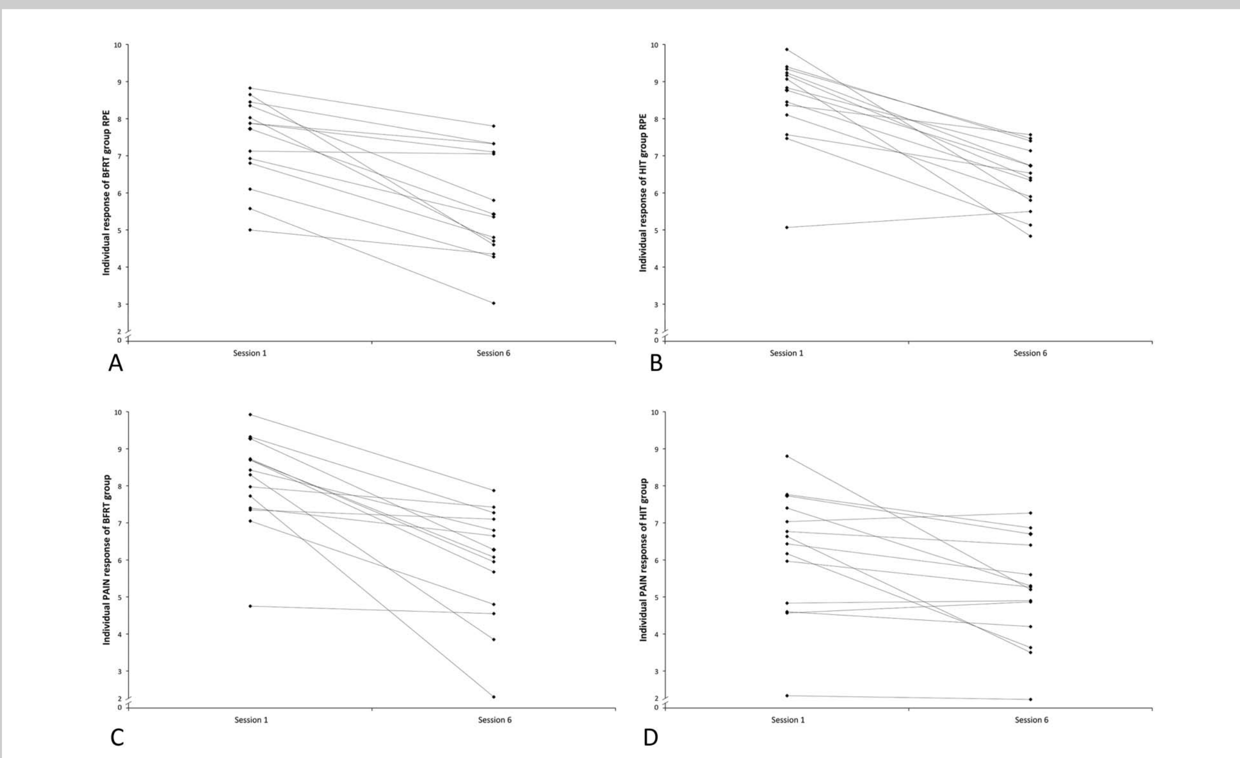

Figure 2. Individual response of ratings of perceived exertion (RPE) and PAIN in blood flow restriction training (BFRT) and high-intensity training (HIT) groups. A) Individual response of RPE in BFRT group. B) Individual response of RPE in HIT group. C) Individual response of PAIN in BFRT group. D) Individual response of PAIN in HIT group.

Table 1. CR10+ PAIN values after each session of BFRT and HIT.*†

	Session 1	Session 2	Session 3	Session 4	Session 5	Session 6
BFRT						
Mean	8.12	7.67	7.44	6.96	6.36‡	5.90§
SD	1.27	1.42	1.44	1.04	1.26	1.55
HIT						
Mean	6.22	6.76	5.96	5.88	5.40‖	5.14‖
SD	1.67	1.58	1.86	1.83	1.68	1.42

*BFRT = blood flow restriction training; HIT = high-intensity training.
†Each session PAIN is expressed as the average PAIN of all sets.
‡Significantly different from session 1 ($p < 0.01$).
§Significantly different from session 1 ($p < 0.001$).
‖Significantly different from session 2 ($p < 0.01$).

In terms of total training volume, BFRT group performed 75 repetitions per session with a load of 13 ± 2 kg (mean ± *SD*) to yield a total volume of 1,026 ± 184 kg, and HIT group performed 24 repetitions per session, with a load of 56 ± 9 kg corresponding to a total volume of 1,360 ± 242 kg. Only 1 subject failed to complete the last 2 repetitions of the last exercise set of session 1 in the BFRT group. Three subjects failed to complete the last repetition of the last exercise set of session 2 in the HIT group.

Rate of Perceived Exertion

Mean RPE was calculated as the average RPE value of all sets in a single session. Mean RPE showed both time ($p < 0.001$; η^2: 0.583) and group effects ($p \leq 0.05$; η^2: 0.204). No time-by-group interactions were detected ($p = 0.902$; η^2: 0.012).

After BFRT, mean RPE reached 7.4 ± 1.2 in session 1 (Figure 1) and significantly decreased by session 5 (−1.4 ± 1.3, $p < 0.01$) and session 6 (−1.7 ± 1.1, $p < 0.001$). After HIT, mean RPE reached 8.5 ± 1.2 in session 1 and significantly dropped in session 4 (−0.9 ± 0.8, $p \leq 0.05$), session 5 (−1.6 ± 1.2, $p < 0.01$), and session 6 (−2.1 ± 1.2, $p < 0.001$).

Pain

Mean PAIN was calculated as the average PAIN value of all sets in a single session. There were both time ($p < 0.001$; η^2: 0.403) and group ($p \leq 0.05$; η^2: 0.187) main effects, although no time-by-group interactions were observed ($p = 0.147$; η^2: 0.060) (Figure 2).

Mean PAIN significantly decreased in session 5 (−1.8 ± 1.4, $p < 0.01$) and session 6 (−2.2 ± 1.5, $p < 0.001$) with respect to session 1 in the BFRT group. High-intensity training group mean PAIN peaked in session 2 and dropped during session 5 and session 6 (−1.4 ± 1 and −1.6 ± 1.1, respectively, $p < 0.01$) as compared with session 2 (Table 1).

Discussion

Previous studies have shown BFRT to result in marked perceptual responses in novel practitioners. However, to date no study has assessed whether these sensory perceptions could be attenuated with continuous practice. The major finding of the present study was that perceptual responses were attenuated after consecutive sessions of BFRT, indicating that an adaptive plasticity exists for the subjective perception of physical exertion and muscle pain, respectively, during BFRT. Moreover, the time course of this adaptive response seems to be similar between BFRT and traditional heavy resistance training (HIT). Ratings of perceived exertion started to decline in the third training session in both BFRT and HIT groups. These decreases reached statistical significance in sessions 4 and 5, respectively. Similar results were observed regarding the attenuation of PAIN. Given that 1RM was not readjusted over the 6 training sessions, a reduction in RPE and PAIN perception perhaps could be expected during the time course of continuous practice, caused by a decrease in relative training intensity in consequence of increased maximal muscle strength. However, decrements in perceptual responses are not likely to be explained by increases in muscle strength in such a short time lapse, considering that subjects underwent only 6 training sessions to a fixed number of repetitions. A potential learning effect was controlled by a 2-week familiarization period.

The lack of significant time-by-group interactions indicates that RPE and PAIN behaved similarly over time in both BFRT and HIT groups. However, the group effect indicates that RPE values were significantly higher with HIT as compared with BFRT (Figure 1). One could speculate that elevated levels of exertion registered with HIT could be attributed to a more pronounced feeling of strain in active muscles, tendons, and joints induced by the high level of mechanical loading (16,27) and to a higher total amount of work. Furthermore, only 1 subject reached volitional failure in the last set of the first training session under occlusion, whereas 3 subjects reached muscular failure in the third set after HIT. Contrary to what has been observed with RPE, BFRT qualitatively seemed to induce higher levels of PAIN as compared with HIT; however, these differences did not reach statistical significance. PAIN was described by subjects as a sensation of deep burning. This perception is likely associated with local hypoxiclike conditions inducing ischemiclike pain via activation of group III and IV afferents. High-intensity muscle contractions are known to occlude arterial inflow, but this occlusion is reversed during the brief relaxation phases occurring at the end of ROM and during resting intervals between sets (43). However, as with BFRT, the cuff was not removed during the rest periods, the more prolonged time under occlusion may explain this trend. Indeed, occlusion pressure has shown to directly influence arterial inflow, resulting in greater perceptual responses as compared with lower occlusion pressures (29). Finally, experiments using a removal of the occlusion cuff during between-set rest periods have been shown to further decrease the perception of effort (45).

There are several physiological factors that are related to altered perceptions of effort, such as feed-forward muscle activation, fatigue, or metabolite production (16,27). In support of this notion, BFRT has shown to impact muscle metabolism (10,31) and fatigue (43) as compared with the same exercise performed without occlusion. The application of pressure through a restrictive cuff reduces arterial inflow and blocks venous clearance from the exercising limb. The physiological mechanisms underlying low-load BFRT are yet to be fully understood, although increased mixed protein synthesis (10) and activation of myogenic satellite stem cells (26) have been demonstrated with acute and longitudinal BFRT. In terms of neuromuscular drive, a reduction in oxygen supply along with a loss of contraction efficiency (23) may increase the overall muscle activity, further stimulating the recruitment of high-threshold motor units (31). This increment of muscle activity has shown to increase the anaerobic metabolic demand and may, thus, lead to increased metabolite production. The suppression of venous metabolic clearance ultimately causes an increase in metabolic byproduct accumulation in the limb distal to the cuff (32). According to Hollander et al. (14), one might speculate that ischemic pain, coupled with decreased metabolite clearance and artery deformation could create an enhanced perception of pain and exertion, respectively. Among the potential limitations of the present study, we did not control selected physiological variables, such as muscle fatigue, active muscle mass, lactate production, or stressing hormones such as cortisol, that are likely to influence the perceptual response to exercise (18).

Although BFRT has previously been demonstrated to be potentially effective in the field of clinical rehabilitation, there is an increased awareness of the psychological factors associated with this training method. In this study, perceptual responses of RPE and PAIN were measured during 6 consecutive sessions of BFRT and traditional HIT. To the best of our knowledge, previous literature has assessed RPE and pain after a single session of BFRT only. In line with those studies, marked perceptual responses were observed in the present experiment and were attenuated when repeated training sessions were performed after the first session. Notably, our RPE values seem well within the range of exertion levels previously described in the literature, especially those of Rossow et al. (29) and Yasuda et al. (48), who reported RPE to reach submaximal values after a single bout of BFRT. Both these studies used the same BFRT program that we used in the present study, involving light loads (20% 1RM) with the first set consisting of 30 repetitions followed by 3 sets of 15 repetitions. Reducing the number of repetitions completed in the exercise session (i.e., suppressing the first 30 repetitions set) has been shown to reduce the level of perceived effort to *moderate* using the CR-10 scale (41). In contrast, performing 3 sets of leg extension exercise to failure results in near-maximal perceived exertion (21).

In view of the results presented here, our study has potential limitations. First, applying the same pressure of 110 mm Hg to every subject independent of limb size is important to consider given what is known about the relationship between limb size and the amount of blood flow restriction occurring (17). Regardless, the results still suggest that despite likely differences in restriction from using an arbitrary pressure, the subjects as a whole still rated RPE and pain to be reduced over time. Further limitations include the lack of obtaining selected physiological variables of relevance for peripheral muscle pain and RPE. This could have potentially helped to explain the main determinants of perceived effort, pain, and their attenuation after BFRT. Also, given that our results were limited to a sample of young, healthy, physically active males, caution is recommended when extrapolating them to clinical populations. Another possible limitation of this study was that the training load was not adjusted during training and that the decline of RPE and PAIN in the last sessions might be partially because of increased strength levels. Lastly, a steady state of RPE and PAIN was not reached within the 6 training sessions presently performed. Future research studies should be conducted to examine how increases in absolute workload might influence the time course of sensory adaptations to BFRT during a longer training period.

In summary, the present study demonstrated that low-load BFRT induces a marked acute response of perceived exertion and pain, which is comparable with that observed with traditional HIT. However, the high levels of perceived exertion and pain registered during the initial training sessions become attenuated in successive training sessions, eventually leading to moderate scores of effort and pain, which are also similar to those of HIT. These results suggest that low-load BFRT may provide a viable option for rehabilitating and/or aged subjects and should not necessarily be limited to the highly motivated individuals only.

Practical Applications

Previous literature has reported a variety of unpleasant feelings associated with BFRT, ranging from high perceived exertion scores to burning and/or pain in the exercising limb. Although other concerns regarding cardiovascular safety have to be considered before participation in BFRT programs, our results indicate that perceptual responses should not discourage strength and conditioning professionals from applying BFRT in inexperienced populations. In addition, novice practitioners should be informed about the high perceptual responses that can be expected in the first stages of the exercise program.

Acknowledgments

The authors thank all participants for their patience and efforts.

References

1. Abe, T, Kearns, CF, and Sato, Y. Muscle size and strength are increased following walk training with restricted venous blood flow from the leg muscle, Kaatsu-walk training. *J Appl Physiol (1985)* 100: 1460–1466, 2006.
2. Abe, T, Sakamaki, M, Fujita, S, Ozaki, H, Sugaya, M, Sato, Y, and Nakajima, T. Effects of low-intensity walk training with restricted leg blood flow on muscle strength and aerobic capacity in older adults. *J Geriatr Phys Ther* 33: 34–40, 2010.
3. ACSM. American College of Sports Medicine position stand. Progression models in resistance training for healthy adults. *Med Sci Sports Exerc* 41: 687–708, 2009.
4. Burd, NA, West, DW, Staples, AW, Atherton, PJ, Baker, JM, Moore, DR, Holwerda, AM, Parise, G, Rennie, MJ, Baker, SK, and Phillips, SM. Low-load high volume resistance exercise stimulates muscle protein synthesis more than high-load low volume resistance exercise in young men. *PLoS One* 5: e12033, 2010.
5. Clark, BC, Manini, TM, Hoffman, RL, Williams, PS, Guiler, MK, Knutson, MJ, McGlynn, ML, and Kushnick, MR. Relative safety of 4 weeks of blood flow-restricted resistance exercise in young, healthy adults. *Scand J Med Sci Sports* 21: 653–662, 2011.
6. Cook, SB, Kanaley, JA, and Ploutz-Snyder, LL. Neuromuscular function following muscular unloading and blood flow restricted exercise. *Eur J Appl Physiol* 114: 1357–1365, 2014.
7. Ekkekakis, P, Parfitt, G, and Petruzzello, SJ. The pleasure and displeasure people feel when they exercise at different intensities: Decennial update and progress towards a tripartite rationale for exercise intensity prescription. *Sports Med* 41: 641–671, 2011.
8. Fahs, CA, Loenneke, JP, Rossow, LM, Thiebaud, RS, and Bembem, MG. Methodological considerations for blood flow restricted resistance exercise. *J Trainol* 1: 14–22, 2012.
9. Fitschen, PJ, Kistler, BM, Jeong, JH, Chung, HR, Wu, PT, Walsh, MJ, and Wilund, KR. Perceptual effects and efficacy of intermittent or continuous blood flow restriction resistance training. *Clin Physiol Funct Imaging* 34: 356–363, 2014.
10. Fujita, S, Abe, T, Drummond, MJ, Cadenas, JG, Dreyer, HC, Sato, Y, Volpi, E, and Rasmussen, BB. Blood flow restriction during low-intensity resistance exercise increases S6K1 phosphorylation and muscle protein synthesis. *J Appl Physiol (1985)* 103: 903–910, 2007.
11. Goldfarb, AH, Garten, RS, Chee, PD, Cho, C, Reeves, GV, Hollander, DB, Thomas, C, Aboudehen, KS, Francois, M, and Kraemer, RR. Resistance exercise effects on blood glutathione status and plasma protein carbonyls: Influence of partial vascular occlusion. *Eur J Appl Physiol* 104: 813–819, 2008.
12. Gualano, B, Neves, M Jr, Lima, FR, Pinto, AL, Laurentino, G, Borges, C, Baptista, L, Artioli, GG, Aoki, MS, Moriscot, A, Lancha, AH Jr, Bonfa, E, and Ugrinowitsch, C. Resistance training with vascular occlusion in inclusion body myositis: A case study. *Med Sci Sports Exerc* 42: 250–254, 2010.
13. Heath, EM. Borg's perceived exertion and pain scales. *Med Sci Sports Exerc* 30: 1461, 1998.
14. Hollander, DB, Reeves, GV, Clavier, JD, Francois, MR, Thomas, C, and Kraemer, RR. Partial occlusion during resistance exercise alters effort sense and pain. *J Strength Cond Res* 24: 235–243, 2010.
15. Laurentino, GC, Ugrinowitsch, C, Roschel, H, Aoki, MS, Soares, AG, Neves, M Jr, Aihara, AY, Fernandes Ada, R, and Tricoli, V. Strength training with blood flow restriction diminishes myostatin gene expression. *Med Sci Sports Exerc* 44: 406–412, 2012.
16. Lins-Filho Ode, L, Robertson, RJ, Farah, BQ, Rodrigues, SL, Cyrino, ES, and Ritti-Dias, RM. Effects of exercise intensity on rating of perceived exertion during a multiple-set resistance exercise session. *J Strength Cond Res* 26: 466–472, 2012.
17. Loenneke, JP, Abe, T, Wilson, JM, Thiebaud, RS, Fahs, CA, Rossow, LM, and Bemben, MG. Blood flow restriction: An evidence based progressive model (review). *Acta Physiol Hung* 99: 235–250, 2012.
18. Loenneke, JP, Balapur, A, Thrower, AD, Barnes, JT, and Pujol, TJ. The perceptual responses to occluded exercise. *Int J Sports Med* 32: 181–184, 2011.
19. Loenneke, JP, Fahs, CA, Rossow, LM, Thiebaud, RS, Mattocks, KT, Abe, T, and Bemben, MG. Blood flow restriction pressure recommendations: A tale of two cuffs. *Front Physiol* 4: 249, 2013.
20. Loenneke, JP, Thiebaud, RS, and Abe, T. Does blood flow restriction result in skeletal muscle damage? A critical review of available evidence. *Scand J Med Sci Sports* 24: e415–422, 2014.
21. Loenneke, JP, Thiebaud, RS, Fahs, CA, Rossow, LM, Abe, T, and Bemben, MG. Blood flow restriction: Effects of cuff type on fatigue and perceptual responses to resistance exercise. *Acta Physiol Hung* 101: 158–166, 2014.
22. Loenneke, JP, Wilson, JM, Marin, PJ, Zourdos, MC, and Bemben, MG. Low intensity blood flow restriction training: A meta-analysis. *Eur J Appl Physiol* 112: 1849–1859, 2012.
23. Manini, TM and Clark, BC. Blood flow restricted exercise and skeletal muscle health. *Exerc Sport Sci Rev* 37: 78–85, 2009.
24. Martin-Hernandez, J, Marin, PJ, Menendez, H, Ferrero, C, Loenneke, JP, and Herrero, AJ. Muscular adaptations after two different volumes of blood flow-restricted training. *Scand J Med Sci Sports* 23: e114–120, 2013.
25. Martin-Hernandez, J, Marin, PJ, Menendez, H, Loenneke, JP, Coelho-e-Silva, MJ, Garcia-Lopez, D, and Herrero, AJ. Changes in muscle architecture induced by low load blood flow restricted training. *Acta Physiol Hung* 100: 411–418, 2013.
26. Nielsen, JL, Aagaard, P, Bech, RD, Nygaard, T, Hvid, LG, Wernbom, M, Suetta, C, and Frandsen, U. Proliferation of myogenic stem cells in human skeletal muscle in response to low-load resistance training with blood flow restriction. *J Physiol* 590: 4351–4361, 2012.
27. O'Sullivan, SB. Perceived exertion. A review. *Phys Ther* 64: 343–346, 1984.
28. Ogasawara, R, Loenneke, JP, Thiebaud, RS, and Abe, T. Low-load bench press training to fatigue results in muscle hypertrophy similar to high-load bench press training. *Int J Clin Med* 4: 114–121, 2013.
29. Rossow, LM, Fahs, CA, Loenneke, JP, Thiebaud, RS, Sherk, VD, Abe, T, and Bemben, MG. Cardiovascular and perceptual responses to blood-flow-restricted resistance exercise with differing restrictive cuffs. *Clin Physiol Funct Imaging* 32: 331–337, 2012.
30. Shimano, T, Kraemer, WJ, Spiering, BA, Volek, JS, Hatfield, DL, Silvestre, R, Vingren, JL, Fragala, MS, Maresh, CM, Fleck, SJ, Newton, RU, Spreuwenberg, LPB, and Häkkinen, K. Relationship between the number of repetitions and selected percentages of one repetition maximum in free weight exercises in trained and untrained men. *J Strength Cond Res* 20: 819–823, 2006.

31. Suga, T, Okita, K, Morita, N, Yokota, T, Hirabayashi, K, Horiuchi, M, Takada, S, Takahashi, T, Omokawa, M, Kinugawa, S, and Tsutsui, H. Intramuscular metabolism during low-intensity resistance exercise with blood flow restriction. *J Appl Physiol (1985)* 106: 1119–1124, 2009.
32. Takarada, Y, Nakamura, Y, Aruga, S, Onda, T, Miyazaki, S, and Ishii, N. Rapid increase in plasma growth hormone after low-intensity resistance exercise with vascular occlusion. *J Appl Physiol (1985)* 88: 61–65, 2000.
33. Takarada, Y, Takazawa, H, and Ishii, N. Applications of vascular occlusion diminish disuse atrophy of knee extensor muscles. *Med Sci Sports Exerc* 32: 2035–2039, 2000.
34. Takarada, Y, Takazawa, H, Sato, Y, Takebayashi, S, Tanaka, Y, and Ishii, N. Effects of resistance exercise combined with moderate vascular occlusion on muscular function in humans. *J Appl Physiol (1985)* 88: 2097–2106, 2000.
35. Tanimoto, M and Ishii, N. Effects of low-intensity resistance exercise with slow movement and tonic force generation on muscular function in young men. *J Appl Physiol (1985)* 100: 1150–1157, 2006.
36. Thiebaud, RS, Loenneke, JP, Fahs, CA, Rossow, LM, Kim, D, Abe, T, Anderson, MA, Young, KC, Bemben, DA, and Bemben, MG. The effects of elastic band resistance training combined with blood flow restriction on strength, total bone-free lean body mass and muscle thickness in postmenopausal women. *Clin Physiol Funct Imaging* 33: 344–352, 2013.
37. Umbel, JD, Hoffman, RL, Dearth, DJ, Chleboun, GS, Manini, TM, and Clark, BC. Delayed-onset muscle soreness induced by low-load blood flow-restricted exercise. *Eur J Appl Physiol* 107: 687–695, 2009.
38. Van Dieen, JH, Ogita, F, and De Haan, A. Reduced neural drive in bilateral exertions: A performance-limiting factor?. *Med Sci Sports Exerc* 35: 111–118, 2003.
39. Van Roie, E, Bautmans, I, Coudyzer, W, Boen, F, and Delecluse, C. Low- and high-resistance Exercise: Long-term adherence and motivation among older adults. *Gerontology* 61: 551–560, 2015.
40. Vieira, A, Gadelha, AB, Ferreira-Junior, JB, Vieira, CA, Soares Ede, M, Cadore, EL, Wagner, DR, and Bottaro, M. Session rating of perceived exertion following resistance exercise with blood flow restriction. *Clin Physiol Funct Imaging* 35: 323–327, 2015.
41. Weatherholt, A, Beekley, M, Greer, S, Urtel, M, and Mikesky, A. Modified Kaatsu training: Adaptations and subject perceptions. *Med Sci Sports Exerc* 45: 952–961, 2013.
42. Wernbom, M, Augustsson, J, and Raastad, T. Ischemic strength training: A low-load alternative to heavy resistance exercise?. *Scand J Med Sci Sports* 18: 401–416, 2008.
43. Wernbom, M, Augustsson, J, and Thomee, R. Effects of vascular occlusion on muscular endurance in dynamic knee extension exercise at different submaximal loads. *J Strength Cond Res* 20: 372–377, 2006.
44. Wernbom, M, Augustsson, J, and Thomee, R. The influence of frequency, intensity, volume and mode of strength training on whole muscle cross-sectional area in humans. *Sports Med* 37: 225–264, 2007.
45. Wernbom, M, Jarrebring, R, Andreasson, MA, and Augustsson, J. Acute effects of blood flow restriction on muscle activity and endurance during fatiguing dynamic knee extensions at low load. *J Strength Cond Res* 23: 2389–2395, 2009.
46. Wilson, JM, Lowery, RP, Joy, JM, Loenneke, JP, and Naimo, MA. Practical blood flow restriction training increases acute determinants of hypertrophy without increasing indices of muscle damage. *J Strength Cond Res* 27: 3068–3075, 2013.
47. Yasuda, T, Fukumura, K, Uchida, Y, Koshi, H, Iida, H, Masamune, K, Yamasoba, T, Sato, Y, and Nakajima, T. Effects of low-load, elastic band resistance training combined with blood flow restriction on muscle size and arterial stiffness in older adults. *J Gerontol A Biol Sci Med Sci* 70: 950–958, 2015.
48. Yasuda, T, Loenneke, JP, Ogasawara, R, and Abe, T. Influence of continuous or intermittent blood flow restriction on muscle activation during low-intensity multiple sets of resistance exercise. *Acta Physiol Hung* 100: 419–426, 2013.