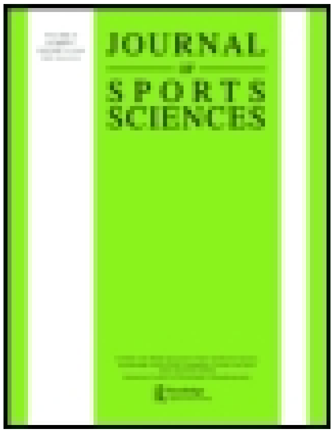

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The effects of resistance exercise with and without different degrees of blood-flow restriction on perceptual responses

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Abstract
The aim was to compare exercise with and without different degrees of blood-flow restriction on perceived exertion (RPE) and discomfort. Participants were assigned to Experiment 1, 2, or 3. Each completed protocols differing by pressure, load, and/or volume. RPE and discomfort were taken before and after each set. For pressure and RPE, the 20% one repetition maximum (1RM) blood-flow restriction conditions were affected by increasing the pressure from 40% to 50% blood-flow restriction (~12 vs. ~14). This did not appear to happen within the 30% 1RM blood-flow restriction conditions or the higher pressures in the 20% 1RM conditions. The similar RPE between 20% and 30% 1RM to failure was expected given both were to failure. For discomfort, ratings were primarily affected by load at the lowest pressure. Increasing pressure to 50% blood-flow restriction increased discomfort at 20% 1RM (~2.6 vs. ~4). There was a further increase when increasing to 60% blood-flow restriction (~4 vs. ~4.8). The high-load condition had the lowest discomfort, while ratings were highest with 20% 1RM to failure. In conclusion, exercise with blood-flow restriction does not appear to augment the perceptual response observed with low-load exercise to failure.

Keywords: *KAATSU, occlusion training, RPE, discomfort*

Introduction

Blood-flow restriction in combination with resistance exercise has been shown to result in muscle hypertrophy and strength gain across a variety of populations, including the elderly (Takarada et al., 2000), highly trained athletes (Takarada, Sato, & Ishii, 2002), those recovering from injuries (e.g. ACL, osteochondral fracture, etc.) (Lejkowski & Pajaczkowski, 2011; Loenneke, Young, Wilson, & Andersen, 2013), as well as a patient diagnosed with an idiopathic inflammatory myopathy (Gualano et al., 2010). These muscular benefits have been observed independent of a high load (~20–30% concentric one repetition maximum (1RM)) and the stimulus appears to be relatively safe (Loenneke, Thiebaud, & Abe, 2014; Loenneke, Wilson, Wilson, Pujol, & Bemben, 2011). The mechanisms behind these effects are not fully known but have been discussed in detail previously (Loenneke, Abe, et al., 2012; Loenneke, Wilson, & Wilson, 2010). However, when designing exercise protocols it is important to identify not only the physiologic responses but also the perceptual responses to that exercise. If two protocols produce similar physiologic responses but one has exaggerated ratings of perceived exertion (RPE) and discomfort, it stands to reason that the task with lower levels of RPE and discomfort would be more efficacious. This may be particularly important for populations that may be contraindicated to participate in higher load exercise.

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All data were collected in the Neuromuscular Laboratory at the University of Oklahoma.
JPL, TA, RDL, DAB, and MGB designed the study.
JPL, DK, CAF, and RST collected the data.
JPL, DK, CAF, RST, TA, RDL, DAB, and MGB analysed and interpreted the data.
JPL, DK, CAF, RST, TA, RDL, DAB, and MGB wrote and edited the manuscript.

Previous research suggests that the perceptual response to resistance exercise may be higher with blood-flow restriction compared to non-blood-flow restricted resistance exercise, despite completing a lower volume of work with blood-flow restriction (Loenneke, Balapur, Thrower, Barnes, & Pujol, 2011). For example, when participants completed two sets of low-load (30% 1RM) knee extension exercise to failure with and without blood-flow restriction from knee wraps, the RPE was higher following both sets of resistance exercise with blood-flow restriction. In addition, the rating of discomfort was similar following the first set but was significantly elevated following the second set with blood-flow restriction. These differences were observed despite the low-load group without blood-flow restriction completing significantly more work. This study was in agreement with Hollander et al. (2010) who demonstrated low loads (30%1RM) combined with blood-flow restriction altered perceptual ratings similarly to that observed with higher intensity exercise (70%1RM). However, it is important to note that these studies used failure protocols and exercising to failure does not appear to be requisite for increases in muscle size and function with blood-flow restriction (Laurentino et al., 2012; Martín-Hernández et al., 2013). Furthermore, making the pressure relative to individual's leg circumference may result in a more uniform response across participants (Loenneke, Fahs, et al., 2012). For example, previous studies not accounting for limb size may have been causing much greater restriction than necessary in participants with smaller limbs (Cook, Kanaley, & Ploutz-Snyder, 2014; Karabulut, Sherk, Bemben, & Bemben, 2013; Manimmanakorn, Hamlin, Ross, Taylor, & Manimmanakorn, 2013). It is important to characterise these perceptual responses to resistance exercise, especially since recent evidence suggests that muscle hypertrophy can occur with low loads in the absence of blood-flow restriction, provided it is taken to failure (Fahs et al., 2014; Mitchell et al., 2012; Van Roie, Delecluse, Coudyzer, Boonen, & Bautmans, 2013). If blood-flow restriction protocols result in higher perceptual responses, then it may be more efficacious to have participants exercise to failure in the absence of blood-flow restriction. This has been hypothesised previously in a recent letter to the editor (Burd, Moore, Mitchell, & Phillips, 2013): "Overall, we hope that it becomes common sense that lifting a low load to voluntary failure is simply a milder form of low-load blood-flow restrictive exercise, with both forms of exercise eventually resulting in maximal muscle fibre activation, that will lead to muscle hypertrophy after training." Thus, the purpose of this study was to determine what effect low-load resistance exercise, with and without different relative degrees of blood-flow restriction (i.e. relative to limb circumference), will have on the acute perceptual response to resistance exercise. To investigate this across several different conditions, we ran three experiments with three separate groups of physically active men.

Methods

Participants

Forty-five physically active men aged 18–35 years were recruited to participate in this study. Physical activity of each participant was determined by self-report. Physically active was defined as being active three or more days per week with a whole body resistance training component two or more days per week for at least the last three months. Participants who were hypertensive (> 140/90 mmHg), used tobacco regularly within past 6 months, or had a body mass index equal to or greater than 30 kg · m^{-2} along with another risk factor for thromboembolism, were excluded (Motykie et al., 2000). Of those initial 45, only 40 completed all of the testing sessions. Two participants were excluded following the initial visit because they had resting supine blood pressures ≥140/90 mmHg. One participant sustained a knee injury prior to visits 2–5 and was excluded from further participation. One participant sustained a hamstring injury following visit 2 and withdrew from further participation. Both of these injuries occurred outside of the laboratory and were not related to this research study. One participant completed the first three visits but was unable to schedule the fourth within the required 5–10 day window. Thus, he was excluded from all further analyses. The study received approval from the university's institutional review board, and each participant gave written informed consent before participation. Muscle activation data are reported in a separate study (Loenneke, Kim, et al., 2014).

Study design

During initial screening visit, participants had their height (to the nearest 0.5 cm) and body mass (to the nearest 0.1 kg) measured to calculate body mass index. Next, blood pressure and ankle brachial index were measured in the supine position to exclude those who may be hypertensive or those who had indications of peripheral vascular disease. Following this, thigh circumference was measured in supine position on the non-dominant leg to determine the pressure that would be used during the resistance exercise bouts with blood-flow restriction. Participants were then tested for their bilateral concentric 1RM on the knee extension machine (NT 1220, Nautilus, Louisville, CO, USA). After

Table I. Exercise protocols.

	1RM (%)	Protocol	Arterial Occ. (%)
Experiment 1			
Condition 1	70	4 × 10	0
Condition 2	20	30–15–15–15	40
Condition 3	30	30–15–15–15	40
Condition 4	0	0	0
Experiment 2			
Condition 1	30	4 × Failure	0
Condition 2	20	30–15–15–15	50
Condition 3	30	30–15–15–15	50
Condition 4	0	0	0
Experiment 3			
Condition 1	20	4 × Failure	0
Condition 2	20	30–15–15–15	60
Condition 3	30	30–15–15–15	60
Condition 4	0	0	0

Note: %1RM = percentage of one repetition maximum; %Arterial Occ. = percentage of estimated arterial occlusion

recording a successful 1RM attempt, participants were familiarised with the cadence of the exercise using a metronome and completed two submaximal (30% 1RM, 2 sets of 10) sets under blood-flow restriction (60% estimated arterial occlusion) to familiarise them with the stimulus. Participants were then scheduled for their first of four visits (three exercise conditions, one control, Table I) with a minimum of five and a maximum of 10 days between visits. To set condition order, a sequence generator (Random.org) was used where the smallest value was one and the largest value was four (corresponding to condition number in Table I). This was generated for each participant. The individual conditions within each of the experiments will be abbreviated in the results and discussion as follows:

Experiment 1 (n = 14): High Load = 70% 1RM (non-blood-flow restriction); 20%/40 blood-flow restriction = 20% 1RM, 40% estimated arterial occlusion pressure; and 30%/40 blood-flow restriction = 30% 1RM, 40% estimated arterial occlusion pressure.

Experiment 2 (n = 14): 30% = 30% 1RM to failure (non-blood-flow restriction); 20%/50; blood-flow restriction = 20% 1RM, 50% estimated arterial occlusion pressure; and 30%/50 blood-flow restriction = 30% 1RM, 50% estimated arterial occlusion pressure.

Experiment 3 (n = 12): 20% = 20% 1RM to failure (non-blood-flow restriction); 20%/60 blood-flow restriction = 20% 1RM, 60% estimated arterial occlusion pressure; and 30%/60 blood-flow restriction = 30% 1RM, 60% estimated arterial occlusion pressure.

Resistance exercise protocols

Participants were randomly assigned to one of the three experiments. Once assigned, participants completed all of the protocols in random order within that experiment. The protocols were comparing exercise load, differing degrees of blood-flow restriction, and exercise volume. Differing degrees of blood-flow restriction were chosen to determine if a dose response could be observed across restrictive pressures. The maximum pressure was set at 60% of estimated arterial occlusion as this has been previously shown to result in high levels of fatigue post exercise, with many of the participants unable to complete the goal amount of repetitions (Loenneke et al., 2013a). The high-load protocol was completed with 1 min rest between sets. All other protocols were separated by 30 s rest periods between sets. A metronome was used to ensure that the participants held the cadence of 1 s for the concentric muscle action and 1 s for the eccentric muscle action during bilateral knee extension exercises. During control conditions, participants rested in the knee extension device but did not exercise. RPE and discomfort were quantified before exercise and following every set of exercise. In the control condition, RPE and discomfort were quantified every minute throughout the rest period. The pre-value was taken prior to putting the cuffs on.

Thigh circumference (33%)

The circumference of the non-dominant thigh was measured with a tape measure at the 33% site between the top of the patella (knee cap) and inguinal crease. The 33% site was measured on the initial visit in the supine position to determine the inflation pressure.

One repetition maximum (1RM)

The maximum load that could be lifted through a full range of motion with proper form was assessed and recorded as the concentric 1RM. The bilateral knee extension 1RM was assessed to the nearest 2.3 kg using standard 1RM procedures described previously (Loenneke et al., 2013a). All 1RMs were determined within five attempts and approximately 1 min rest was allotted between attempts.

Blood-flow restriction

With the participants in seated position, the blood-flow restriction cuffs (5 cm, Hokanson, Inc.) were applied to the most proximal portion of each thigh. The cuffs were inflated to 50 mmHg for 30 s and then deflated for 10 s. The cuffs were then inflated to

Table II. Blood-flow restriction pressures.

Thigh circ.	Pressure used (60% AO)	Pressure used (50% AO)	Pressure used (40% AO)
< 45–50.9 cm	120 mmHg	100 mmHg	80 mmHg
51–55.9 cm	150 mmHg	130 mmHg	100 mmHg
56–59.9 cm	180 mmHg	150 mmHg	120 mmHg
> 60.9 cm	210 mmHg	180 mmHg	140 mmHg

Note: Circ = circumference; AO = estimated arterial occlusion.

100 mmHg for 30 s and then deflated for 10 s (unless 100 mmHg was the target pressure). The cycle of cuff inflation/deflation was repeated with the cuff pressures increasing in increments of 40 mmHg until the target inflation pressure was reached. The cuffs were inflated to the target inflation pressure prior to the first set of exercise and then deflated and removed immediately following the final set of exercise. The final pressure was set to a percentage of arterial occlusion estimated from thigh circumference (Table II). To determine estimated arterial occlusion, we used a previous dataset (Loenneke, Fahs, et al., 2012) and plotted thigh circumference with arterial occlusion. This method is likely imperfect but does appear to provide a relative blood-flow restriction stimulus (Loenneke et al., 2013a). Further, the cuffs used in the current study have previously been shown to provide a stimulus similar to the traditional Kaatsu Master Apparatus applied to an initial pressure of 50 mmHg (cuff pressure applied to limb prior to inflation) at rest (Loenneke et al., 2013b) and during exercise (Loenneke, Thiebaud, et al., 2014).

Ratings of perceived exertion (RPE)

RPE was taken before each exercise bout and following each set using the standard Borg 6–20 scale with methods similar to that of Hollander et al. (2003). Participants were instructed on how to rate RPE prior to each exercise visit. Participants were told, "We want you to rate your perception of exertion, that is, 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 6–20, where 6 means 'no exertion at all' and 20 means 'maximal exertion'; any questions?" Participants confirmed that they fully understood how to rate RPE prior to actual testing.

Ratings of discomfort

A rating of discomfort was taken before each exercise bout and following each set using the Borg discomfort scale (CR-10+). Methods similar to that of Hollander et al. (2003) were used. For example, participants were asked, "What are your worst experiences of discomfort? 'Maximum discomfort (rating of 10)' is your main point of reference; it is anchored by your previously experienced worst discomfort. The worst discomfort that you have ever experienced, the 'Maximum discomfort' may not be the highest possible level of discomfort. There may be a level of discomfort that is still stronger than your 10; if this is the case, you will say 11 or 12. If the discomfort is much stronger, for example, 1.5 times 'Maximum Discomfort' you will say 15; any questions?" Participants confirmed that they fully understood how to rate discomfort prior to actual testing.

Statistical analyses. All data were analysed using the SPSS 18.0 statistical software package (SPSS Inc., Chicago, IL) with variability represented as standard deviation (s). To compare differences in the perceptual responses (RPE and Discomfort), the Friedman non-parametric test was used to determine if differences existed between conditions at different time points (pre, 1st set, 2nd set, 3rd set, 4th set). If significant differences existed, Wilcoxon related samples non-parametric tests were used to determine where the difference occurred. Statistical significance for this test was set at an alpha level of 0.05. All post-hoc comparisons maintained the error rate by Bonferroni correcting the p level.

Results

Experiment 1

Group characteristics. Participants (n = 14) on average were 23 (4) years old, 176 (6) cm tall, 81 (13.6) kg, had a body mass index of 25.9 (3.2) $kg \cdot m^{-2}$, a 1RM of 76.4 (13) kg and a supine measured thigh circumference at the 33% site of 59.4 (6.1) cm.

Ratings of perceived exertion. Friedman non-parametric test found no significant differences between conditions for baseline RPE (Table III, P = 0.999). However, a significant difference was found between conditions for set 1 (P < 0.001), 2 (P < 0.001), 3 (P < 0.001), and 4 (P < 0.001).

Ratings of discomfort. Friedman non-parametric test found no significant differences between conditions for baseline ratings of discomfort (Table IV, P = 0.999). However, a significant difference was found between conditions for set 1 (P < 0.001), 2 (P < 0.001), 3 (P < 0.001), and 4 (P < 0.001).

Total repetitions completed. The number of repetitions completed for each protocol is presented in Table V.

Table III. Ratings of perceived exertion (RPE).

	Pre	Set 1	Set 2	Set 3	Set 4
Experiment 1					
HL	6 (6–6)	12 (8–13)[a]	14 (11–15)[ab]	15 (12–16)[a]	15 (13–17)[a]
20%/40 BFR	6 (6–6)	11(7–13)[a]	13 (9–15)[a]	13 (10–15)[b]	13 (11–15)[b]
30%/40 BFR	6 (6–6)	13 (10–15)[a]	14 (13–17)[b]	15 (14–17)[a]	17 (13–18)[a]
CON	6 (6–6)	6 (6–6)[b]	6 (6–6)[c]	6 (6–6)[c]	6 (6–6)[c]
Experiment 2					
30%	6 (6–6)	14 (13–16)[a]	16 (14–17)[a]	17 (14–17)[a]	18 (15–19)[a]
20%/50 BFR	6 (6–6)	11 (9–13)[b]	14 (11–14)[b]	15 (14–15)[b]	16 (14–17)[b]
30%/50 BFR	6 (6–6)	12 (10–15)[a]	14 (12–17)[a]	15 (14–17)[a]	16 (15–19)[ab]
CON	6 (6–6)	6 (6–6)[c]	6 (6–6)[c]	6 (6–6)[c]	6 (6–6)[c]
Experiment 3					
20%	6 (6–6)	14 (13–15)[a]	16 (15–17)[a]	17 (15–18)[a]	18 (15–19)[a]
20%/60 BFR	6 (6–6)	11 (10–13)[b]	13 (13–15)[a]	15 (14–17)[a]	16 (15–18)[a]
30%/60 BFR	6 (6–6)	13 (10–14)[ab]	13 (15–16)[a]	16 (14–17)[a]	16 (14–19)[a]
CON	6 (6–6)	6 (6–6)[c]	6 (6–6)[b]	6 (6–6)[b]	6 (6–6)[b]

Notes: HL high load (70% maximal effort); 20%/40 BFR = 20% maximal effort at an estimated 40% arterial occlusion pressure; 30%/40 BFR = 30% maximal effort at an estimated 40% arterial occlusion pressure; CON = control; 30% = 30% maximal effort to failure; 20%/50 BFR = 20% maximal effort at an estimated 50% arterial occlusion pressure; 30%/50 BFR = 30% maximal effort at an estimated 50% arterial occlusion pressure; 20% = 20% maximal effort to failure; 20%/60 BFR = 20% maximal effort at an estimated 60% arterial occlusion pressure; 30%/60 BFR = 30% maximal effort at an estimated 60% arterial occlusion pressure. Sets with different letters represent significant differences between conditions ($P \leq 0.05$). Values represented as 50th percentile (25th–75th) percentiles.

Table IV. Ratings of discomfort.

	Pre	Set 1	Set 2	Set 3	Set 4
Experiment 1					
HL	0 (0–0)	2 (0.8–3.2)[ab]	3 (1.7–6)[ab]	3.5 (2.7–7)[a]	5.5 (3.7–7.2)[ab]
20%/40 BFR	0 (0–0)	1 (0.5–3.2)[a]	2.7 (1.3–5)[a]	3 (2.2–5.1)[a]	4 (2.7–6)[a]
30%/40 BFR	0 (0–0)	4 (2.2–6)[b]	5.5 (2.5–8)[b]	7 (3.6–8.2)[b]	7.5 (4.5–9)[b]
CON	0 (0–0)	0 (0–0)[c]	0 (0–0)[c]	0 (0–0)[c]	0 (0–0)[c]
Experiment 2					
30%	0 (0–0)	3 (2.2–4.5)[a]	3.5 (3–7)[a]	5 (3.5–7)[a]	6 (3.5–8)[a]
20%/50 BFR	0 (0–0)	2 (0.8–3)[b]	3 (2.1–5)[a]	5 (2.7–6)[a]	6 (3.5–7)[a]
30%/50 BFR	0 (0–0)	3 (1.7–6)[ab]	5 (2.2–6.5)[a]	5 (3–7.5)[a]	6 (3.5–8.2)[a]
CON	0 (0–0)	0 (0–0)[c]	0 (0–0)[b]	0 (0–0)[b]	0 (0–0)[b]
Experiment 3					
20%	0 (0–0)	4 (2.5–5.7)[a]	5 (3.2–7)[a]	6 (4–7.7)[a]	7 (4.2–8.7)[a]
20%/60 BFR	0 (0–0)	3 (2–3)[a]	4 (3.1–5.7)[a]	5.5 (4–7.7)[a]	7 (5–9)[a]
30%/60 BFR	0 (0–0)	2 (1.2–4)[a]	5 (4–7)[a]	7 (5.2–8)[a]	8 (5.2–9)[a]
CON	0 (0–0)	0 (0–0)[b]	0 (0–0)[b]	0 (0–0)[b]	0 (0–0)[b]

Note: HL = high load (70% one repetition maximum (1RM)); 20%/40 BFR = 20% 1RM at an estimated 40% arterial occlusion pressure; 30%/40 BFR = 30% 1RM at an estimated 40% arterial occlusion pressure; CON = control; 30% = 30% 1RM to failure; 20%/50 BFR = 20% 1RM at an estimated 50% arterial occlusion pressure; 30%/50 BFR = 30% 1RM at an estimated 50% arterial occlusion pressure; 20% = 20% 1RM to failure; 20%/60 BFR = 20% 1RM at an estimated 60% arterial occlusion pressure; 30%/60 BFR = 30% 1RM at an estimated 60% arterial occlusion pressure. Sets with different letters represent significant differences between conditions ($P \leq 0.05$). Values represented as 50th percentile (25th–75th) percentiles.

Experiment 2

Group characteristics. Participants (n = 14) on average were 23 (4) years old, 175 (7) cm tall, 78.9 (14.0) kg, had a body mass index of 25.7 (3.9) $kg \cdot m^{-2}$, a 1RM of 77.6 (17.7) kg and a supine measured thigh circumference at the 33% site of 57.6 (5.5) cm.

Ratings of perceived exertion. Friedman non-parametric test found no significant differences between conditions for baseline RPE (Table III, P = 0.999). However, a significant difference was found between conditions for set 1 (P < 0.001), 2 (P < 0.001), 3 (P < 0.001), and 4 (P < 0.001).

Ratings of discomfort. Friedman non-parametric test found no significant differences between conditions for baseline ratings of discomfort (Table IV, P = 0.999). However, a significant difference was found between conditions for set 1 (P < 0.001), 2 (P < 0.001), 3 (P < 0.001), and 4 (P < 0.001).

Table V. Repetitions completed.

	Repetitions
Experiment 1	
HL	37 (2)
20%/40 BFR	74 (2)
30%/40 BFR	69 (9)
Experiment 2	
30%	91 (18)
20%/50 BFR	74 (2)
30%/50 BFR	67 (10)
Experiment 3	
20%	165 (53)
20%/60 BFR	74 (2)
30%/60 BFR	67 (10)

Notes: 20% 1RM = 20% one repetition maximum (1RM); 30% 1RM = 30% 1RM; 40 BFR = 40% arterial occlusion pressure; 50 BFR = 50% arterial occlusion pressure; 60 BFR = 60% arterial occlusion pressure; non-BFR = non-blood-flow restriction conditions; HL high load (70% 1RM); 20% = 20% 1RM (no BFR); 30% = 30% 1RM (no BFR). Variability represented as standard deviations.

Total repetitions completed. The number of repetitions completed for each protocol is presented in Table V.

Experiment 3

Group characteristics. Participants (n = 12) on average were 21 (3) years old, 179 (6) cm tall, 85.8 (12) kg, had a body mass index of 26.5 (3.8) kg · m^{-2}, a 1RM of 81 (17.1) kg and a supine measured thigh circumference at the 33% site of 60.5 (6.5) cm.

Ratings of perceived exertion. Friedman non-parametric test found no significant differences between conditions for baseline RPE (Table III, P = 0.999). However, a significant difference was found between conditions for set 1 ($P < 0.001$), 2 ($P < 0.001$), 3 ($P < 0.001$), and 4 ($P < 0.001$).

Ratings of discomfort. Friedman non-parametric test found no significant differences between conditions for baseline ratings of discomfort (Table IV, P = 0.999). However, a significant difference was found between conditions for set 1 ($P < 0.001$), 2 ($P < 0.001$), 3 ($P < 0.001$), and 4 ($P < 0.001$).

Total repetitions completed. The number of repetitions completed for each protocol is presented in Table V.

Discussion

The results of the current study suggest that with blood-flow restriction, load appears to modulate RPE and discomfort more so than changing pressure. This effect of load on the perceptual response primarily occurs at 40% of estimated arterial occlusion pressure and its influence appears to diminish at applied pressures of 50% and 60% of estimated arterial occlusion. In addition, the results of these experiments do not support the conjecture that low-load exercise to failure is a "milder" form of blood-flow restricted exercise.

A number of studies have observed increases in RPE with low-load resistance exercise with and without blood-flow restriction (Hollander et al., 2010; Labarbera, Murphy, Laroche, & Cook, 2013; Loenneke et al., 2011, 2013a, Loenneke, Thiebaud, Fahs, et al., 2014; Rossow et al., 2012; Wernbom, Augustsson, & Thomee, 2006; Wernbom, Järrebring, Andreasson, & Augustsson, 2009; Yasuda et al., 2010). Of those studies investigating RPE following blood-flow restriction in combination with resistance exercise, only one has investigated those changes across different pressures (100 mmHg vs. 160 mmHg) and compared them to high-load training. To illustrate, Yasuda et al. (2010) investigated unilateral elbow flexion muscle contractions completed at 20% 1RM (30 repetitions, followed by three sets of 15) and 70% 1RM (three sets to failure). The 160 mmHg condition had higher RPE than the 100 mmHg condition, but the non-blood-flow restricted 70% 1RM condition had the highest ratings. These results are consistent with the findings from the 20% 1RM blood-flow restricted conditions of the current study, where RPE was affected (albeit small) by increasing pressure from 40% to 50% blood-flow restriction (~12 vs. ~14). This did not appear to happen within the 30% 1RM blood-flow restriction conditions or the higher restriction pressures in the 20% 1RM conditions suggesting that the load may be playing a more important role at lower restriction pressures in augmenting RPE. The similar RPE between 20% and 30% 1RM to failure is not surprising considering both conditions were taken to muscular failure for all four sets. In addition, there were no correlations between RPE of the fourth set and post-exercise lactate levels (data not shown). Although this is speculation, this finding may suggest that the increased ratings were due to psychological factors.

When examining the change in discomfort across experiments for each load, the ratings were primarily affected by load at the lowest applied pressure (40% estimated arterial occlusion pressure). Increasing the applied pressure from 40% to 50% blood-flow restriction qualitatively increased ratings of discomfort at 20% 1RM, albeit small (~2.6 vs. ~4). There was a further qualitative increase in the ratings when increasing the applied pressure to 60% blood-flow restriction (~4 vs. ~4.8); however, the meaningfulness of this small increase is unknown. For the non-blood-flow restriction conditions, the high-load condition qualitatively had the lowest ratings of discomfort, while the ratings were highest with the 20% 1RM to failure condition. The difference in discomfort between the failure conditions was likely due to differences in exercise volume. A number of studies have observed increases in ratings of discomfort with low-load resistance exercise with and without blood-flow restriction (Hollander et al., 2010; Labarbera et al., 2013; Loenneke, Balapur, et al., 2011, 2013a, Loenneke, Thiebaud, Fahs, et al., 2014; Rossow et al., 2012; Wernbom et al., 2009). Of those studies, none have investigated the response across different loads or pressures. Two of the studies found no difference in ratings of discomfort between low-load resistance exercise to failure with or without blood-flow restriction (Labarbera et al., 2013; Wernbom et al., 2009). In contrast, Loenneke et al. (2011) reported higher ratings of discomfort with blood-flow restriction to failure compared to the non-blood-flow restriction condition to failure. It is acknowledged that the difference in that study was quite small and the meaningfulness of that observed difference is unknown. When it comes to more traditional resistance training, Hollander et al. (2003) reported similar ratings of discomfort between blood-flow restricted exercise to failure and high-load resistance exercise to failure. Thus, the majority of the studies suggest that ratings of discomfort are similar between exercise to failure with and without blood-flow restriction. The ratings may however be increased when compared to a high-load condition not going to failure as in this study, or when compared to a repetition matched non-blood-flow restricted control (Loenneke et al., 2013a). Secondary analyses found significant direct correlations (rho ≥0.609) between ratings of discomfort of the fourth set and post exercise lactate levels only in Experiment 3 (data not shown). No correlations existed for Experiment 1 or Experiment 2. These analyses may suggest that ratings in Experiment 1 and Experiment 2 may be largely driven by psychological factors, whereas physiologic factors may be playing more of a role with exercise involving higher volume (i.e. 20% to failure) or higher pressure (i.e. estimated 60% blood-flow restriction).

In view of the results presented herein, the set of experiments does possess some limitations. First, the amount of blood-flow restriction was estimated for each participant from previous data collected during supine rest but was not directly measured. This was not done due to the complexities involved with measuring changes in blood flow during exercise of the lower body. Regardless, each participant did receive graded amounts of blood-flow restriction which allowed for the central question of "does applied pressure affect the perceptual response?" to be answered. Second, a comparison across experiments was completed qualitatively. This was due to each experiment being powered to find differences only within each respective experiment. Although it would have been interesting to statistically compare across experiments, qualitative analyses is still useful and is largely how different studies are compared in the literature.

Conclusions

The hypothesis that low-load training to failure is a "milder form of low-load blood-flow restrictive exercise" does not appear to be supported from a perceptual response standpoint. The current results suggest that the perceptual responses are similar despite differences in repetitions completed (i.e. exercise volume). Thus, if high-load resistance exercise or accumulated stress from a high number of repetitive low-load contractions is contraindicated, low-load resistance exercise with blood-flow restriction may offer a physiologic benefit without augmenting the perceptual response observed with low-load exercise to failure. Furthermore, some investigations have based the pressure applied on the individual's perception during exercise (Karabulut, Abe, Sato, & Bemben, 2010). However, given that our findings did not find large perceptual differences during exercise across a variety of pressures, indicates that perception may not provide the best estimate of actual restriction in the lower body. This, however, requires further study.

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Conflict of interest

No conflict of interests to disclose for any authors.

References

Burd, N. A., Moore, D. R., Mitchell, C. J., & Phillips, S. M. (2013). Big claims for big weights but with little evidence. *European Journal of Applied Physiology*, *113*(1), 267–268.

Cook, S. B., Kanaley, J. A., & Ploutz-Snyder, L. L. (2014). Neuromuscular function following muscular unloading and blood flow restricted exercise. *European Journal of Applied Physiology*, *114*(7), 1357–1365.

Fahs, C. A., Loenneke, J. P., Thiebaud, R. S., Rossow, L. M., Kim, D., Abe, T., & Bemben, M. G. (2014). Muscular adaptations to fatiguing exercise with and without blood flow restriction. *Clinical Physiology and Functional Imaging*. Advance online publication. doi:10.1111/cpf.12141

Gualano, B., Neves Jr., M., Lima, F. R., Pinto, A. L., Laurentino, G., Borges, C., … Ugrinowitsch, C. (2010). Resistance training with vascular occlusion in inclusion body myositis: A case study. *Medicine & Science in Sports & Exercise*, *42*(2), 250–254.

Hollander, D. B., Durand, R. J., Trynicki, J. L., Larock, D., Castracane, V. D., Hebert, E. P., & Kraemer, R. R. (2003). RPE, pain, and physiological adjustment to concentric and eccentric contractions. *Medicine & Science in Sports & Exercise*, *35*(6), 1017–1025.

Hollander, D. B., Reeves, G. V., Clavier, J. D., Francois, M. R., Thomas, C., Kraemer, R. R. (2010). Partial occlusion during resistance exercise alters effort sense and pain. *Journal of Strength and Conditioning Research*, *24*(1), 235–243.

Karabulut, M., Abe, T., Sato, Y., & Bemben, M. G. (2010). The effects of low-intensity resistance training with vascular restriction on leg muscle strength in older men. *European Journal of Applied Physiology*, *108*(1), 147–155.

Karabulut, M., Sherk, V. D., Bemben, D. A., & Bemben, M. G. (2013). Inflammation marker, damage marker and anabolic hormone responses to resistance training with vascular restriction in older males. *Clinical Physiology and Functional Imaging*, *33*(5), 393–399.

Labarbera, K. E., Murphy, B. G., Laroche, D. P., & Cook, S. B. (2013). Sex differences in blood flow restricted isotonic knee extensions to fatigue. *The Journal of Sports Medicine and Physical Fitness*, *53*(4), 444–452.

Laurentino, G. C., Ugrinowitsch, C., Roschel, H., Aoki, M. S., Soares, A. G., Neves Jr., M., … Tricoli, V. (2012). Strength training with blood flow restriction diminishes myostatin gene expression. *Medicine & Science in Sports & Exercise*, *44*(3), 406–412.

Lejkowski, P. M., & Pajaczkowski, J. A. (2011). Utilization of vascular restriction training in post-surgical knee rehabilitation: A case report and introduction to an under-reported training technique. *The Journal of the Canadian Chiropractic Association*, *55*(4), 280–287.

Loenneke, J. P., Abe, T., Wilson, J. M., Thiebaud, R. S., Fahs, C. A., Rossow, L. M., & Bemben, M. G. (2012). Blood flow restriction: An evidence based progressive model (Review). *Acta Physiologica Hungarica*, *99*(3), 235–250.

Loenneke, J. P., Balapur, A., Thrower, A. D., Barnes, J. T., & Pujol, T. J. (2011). The perceptual responses to occluded exercise. *International Journal of Sports Medicine*, *32*(3), 181–184.

Loenneke, J. P., Fahs, C. A., Rossow, L. M., Sherk, V. D., Thiebaud, R. S., Abe, T., & Bemben, M. G. (2012). Effects of cuff width on arterial occlusion: Implications for blood flow restricted exercise. *European Journal of Applied Physiology*, *112* (8), 2903–2912.

Loenneke, J. P., Kim, D., Fahs, C. A., Thiebaud, R. S., Abe, T., Larson, R. D., & Bemben, M. G. (2014). Effects of exercise with and without different degrees of blood flow restriction on torque and muscle activation. *Muscle & Nerve*. Advance online publication. doi:10.1002/mus.24448

Loenneke, J. P., Thiebaud, R. S., & Abe, T. (2014). Does blood flow restriction result in skeletal muscle damage? A critical review of available evidence. *Scandinavian Journal of Medicine & Science in Sports*, *24*, e415–422.

Loenneke, J. P., Thiebaud, R. S., Fahs, C. A., Rossow, L. M., Abe, T., & Bemben, M. G. (2013a). Blood flow restriction does not result in prolonged decrements in torque. *European Journal of Applied Physiology*, *113*(4), 923–931.

Loenneke, J. P., Thiebaud, R. S., Fahs, C. A., Rossow, L. M., Abe, T., & Bemben, M. G. (2013b). Effect of cuff type on arterial occlusion. *Clinical Physiology and Functional Imaging*, *33* (4), 325–327.

Loenneke, J. P., Thiebaud, R. S., Fahs, C. A., Rossow, L. M., Abe, T., & Bemben, M. G. (2014). Blood flow restriction: Effects of cuff type on fatigue and perceptual responses to resistance exercise. *Acta Physiologica Hungarica*, *101*(2), 158–166.

Loenneke, J. P., Wilson, G. J., & Wilson, J. M. (2010). A mechanistic approach to blood flow occlusion. *International Journal of Sports Medicine*, *31*(1), 1–4.

Loenneke, J. P., Wilson, J. M., Wilson, G. J., Pujol, T. J., & Bemben, M. G. (2011). Potential safety issues with blood flow restriction training. *Scandinavian Journal of Medicine & Science in Sports*, *21*(4), 510–518.

Loenneke, J. P., Young, K. C., Wilson, J. M., & Andersen, J. C. (2013). Rehabilitation of an osteochondral fracture using blood flow restricted exercise: A case review. *Journal of Bodywork and Movement Therapies*, *17*(1), 42–45.

Manimmanakorn, A., Hamlin, M. J., Ross, J. J., Taylor, R., & Manimmanakorn, N. (2013). Effects of low-load resistance training combined with blood flow restriction or hypoxia on muscle function and performance in netball athletes. *Journal of Science and Medicine in Sport*, *16*(4), 337–342.

Martín-Hernández, J., Marín, P. J., Menéndez, H., Ferrero, C., Loenneke, J. P., & Herrero, A. J. (2013). Muscular adaptations after two different volumes of blood flow-restricted training. *Scandinavian Journal of Medicine & Science in Sports*, *23*(2), e114–120.

Mitchell, C. J., Churchward-Venne, T. A., West, D. W., Burd, N. A., Breen, L., Baker, S. K., … Phillips, S. M. (2012). Resistance exercise load does not determine training-mediated hypertrophic gains in young men. *Journal of Applied Physiology*, *113*(1), 71–77.

Motykie, G. D., Zebala, L. P., Caprini, J. A., Lee, C. E., Arcelus, J. I., Reyna, J., & Cohen, E. B. (2000). A guide to venous thromboembolism risk factor assessment. *Journal of Thrombosis and Thrombolysis*, *9*(3), 253–262.

Rossow, L. M., Fahs, C. A., Loenneke, J. P., Thiebaud, R. S., Sherk, V. D., Abe, T., & Bemben, M. G. (2012). Cardiovascular and perceptual responses to blood-flow-restricted resistance exercise with differing restrictive cuffs. *Clinical Physiology and Functional Imaging*, *32*(5), 331–337.

Takarada, Y., Sato, Y., & Ishii, N. (2002). Effects of resistance exercise combined with vascular occlusion on muscle function in athletes. *European Journal of Applied Physiology*, *86*(4), 308–314.

Takarada, Y., Takazawa, H., Sato, Y., Takebayashi, S., Tanaka, Y., & Ishii, N. (2000). Effects of resistance exercise combined with moderate vascular occlusion on muscular function in humans. *Journal of Applied Physiology*, *88*(6), 2097–2106.

Van Roie, E., Delecluse, C., Coudyzer, W., Boonen, S., & Bautmans, I. (2013). Strength training at high versus low external resistance in older adults: Effects on muscle volume, muscle strength, and force-velocity characteristics. *Experimental Gerontology*, *48*(11), 1351–1361.

Wernbom, M., Augustsson, J., & Thomee, R. (2006). Effects of vascular occlusion on muscular endurance in dynamic knee extension exercise at different submaximal loads. *Journal of Strength and Conditioning Research*, *20*(2), 372–377.

Wernbom, M., Järrebring, R., Andreasson, M. A., & Augustsson, J. (2009). Acute effects of blood flow restriction on muscle activity and endurance during fatiguing dynamic knee extensions at low load. *Journal of Strength and Conditioning Research*, *23*(8), 2389–2395.

Yasuda, T., Abe, T., Brechue, W. F., Iida, H., Takano, H., Meguro, K., … Nakajima, T. (2010). Venous blood gas and metabolite response to low-intensity muscle contractions with external limb compression. *Metabolism: Clinical and Experimental*, *59*(10), 1510–1519.