European Journal of Sport Science, 2018
Vol. 18, No. 6, 772–780, https://doi.org/10.1080/17461391.2018.1450898

ORIGINAL ARTICLE

Effects of different intensities of resistance training with equated volume load on muscle strength and hypertrophy

THIAGO LASEVICIUS[1,2], CARLOS UGRINOWITSCH[2], BRAD JON SCHOENFELD[3], HAMILTON ROSCHEL [2], LUCAS DUARTE TAVARES [1,2], EDUARDO OLIVEIRA DE SOUZA[4], GILBERTO LAURENTINO[2], & VALMOR TRICOLI[2]

[1]*Department of Health Sciences, University Ibirapuera, São Paulo, Brazil;* [2]*Department of Sport, School of Physical Education and Sport, University of São Paulo, São Paulo, Brazil;* [3]*Department of Health Sciences, CUNY Lehman College, Bronx, NY, USA &* [4]*Department of Health Sciences and Human Performance, The University of Tampa, Tampa, FL, USA*

Abstract
The present study investigated the effects of different intensities of resistance training (RT) on elbow flexion and leg press one-repetition maximum (1RM) and muscle cross-sectional area (CSA). Thirty men volunteered to participate in an RT programme, performed twice a week for 12 weeks. The study employed a within-subject design, in which one leg and arm trained at 20% 1RM (G20) and the contralateral limb was randomly assigned to one of the three conditions: 40% (G40); 60% (G60), and 80% 1RM (G80). The G20 started RT session with three sets to failure. After G20 training, the number of sets was adjusted for the other contralateral limb conditions with volume-matched. CSA and 1RM were assessed at pre, post-6 weeks, and post-12 weeks. There was time effect for CSA for the vastus lateralis (VL) (8.9%, 20.5%, 20.4%, and 19.5%) and elbow flexors (EF) (11.4%, 25.3%, 25.1%, and 25%) in G20, G40, G60, and G80, respectively ($p > .05$). G80 showed higher CSA than G20 for VL (19.5% vs. 8.9%) and EF (25% vs. 11.4%) at post-12 weeks ($p < .05$). There was time effect for elbow flexion and unilateral leg press strength for all groups post-12 weeks ($p < .05$). However, the magnitude of increase was higher in G60 and G80. In conclusion, when low to high intensities of RT are performed with volume-matched, all intensities were effective for increasing muscle strength and size; however, 20% 1RM was suboptimal in this regard, and only the heavier RT intensity (80% 1RM) was shown superior for increasing strength and CSA compared to low intensities.

Keywords: *Low-load, high-load, volume of training, muscle size*

Highlights

- Resistance training with intensity ranging 20–80% 1RM are effective to increase strength and muscle hypertrophy. However, low intensity (20% 1RM) was suboptimal for maximizing muscle hypertrophy.
- A wide spectrum of intensities, from 40–80% 1RM, are viable options to increase muscle mass. It is feasible that employing combinations of these intensities may enhance hypertrophic results, as well as allow for better recovery by alleviating joint-related stresses from continuous heavy-load training.
- The initial 6 weeks of training all the studied intensities can produce increases in strength in men with no experience in resistance training. However, if maximizing strength gains over the long-term training is a primary goal, it is necessary employ higher training intensities.

Introduction

Resistance training (RT) is the primary mode of exercise to increase muscle strength and hypertrophy in humans. These increases can positively impact the ability to carry out daily activities (FitzGerald et al., 2004; Rantanen et al., 2002) as well as significantly improve overall health and wellness. Additionally, RT has been shown to be an important strategy for enhancing physical performance in athletics (Los Arcos et al., 2014; Markovic, Jukic, Milanovic, & Metikos, 2007; Pareja-Blanco, Rodríguez-Rosell, Sánchez-Medina, Gorostiaga, & González-Badillo, 2014).

Variables of an RT programme such as rest interval, frequency, volume, and intensity can be

Correspondence: Thiago Lasevicius, Department of Health Sciences, University Ibirapuera, C/Av. Interlagos, 1329, Chácara Flora – São Paulo PC 04661-100, São Paulo, Brazil. E-mail: lasevicius.thiago@gmail.com

manipulated to induce muscular adaptations (American College of Sports Medicine, 2009; Schoenfeld, Grgic, Ogborn, & Krieger, 2017). With respect to intensity, training with loads equating to 65–85% of maximum dynamic strength (1RM) has been recommended to increase strength and muscle mass (American College of Sports Medicine, 2009). Alternatively, several studies have shown that low to moderate intensities (30–50% 1RM) promote similar gains in muscle mass compared to training with higher intensities (Lamon, Wallace, Leger, & Russell, 2009; Leger et al., 2006; Mitchell et al., 2012; Ogasawara, Loenneke, Thiebaud, & Abe, 2013; Schoenfeld, Peterson, Ogborn, Contreras, & Sonmez, 2015). Mitchell et al. (2012) found that leg extension exercise performed at 30% 1RM until failure similarly increased quadriceps muscle volume compared to high-intensity exercise (80% 1RM) and was superior to a 30% 1RM non-failure condition. The authors speculated that this finding was due to complete recruitment of the motor unit pool when low-intensity exercise is performed to volitional failure and with a large volume of training (VT). Alternatively, high-intensity RT resulted in superior strength gains compared to low-intensity exercise (Mitchell et al., 2012). Intriguingly, electromyography research shows greater muscular activation in high- versus low-intensity RT (Schoenfeld, Contreras, Willardson, Fontana, & Tiryaki-Sonmez, 2014), suggesting that full spectrum of motor units may not be fully stimulated when training at lower intensity.

Many studies have sought to compare muscular adaptations with low- versus high-intensity RT. Some have found greater increases in muscle hypertrophy with heavier intensity (Campos et al., 2002; Holm et al., 2008; Schuenke et al., 2012), while others showed no significant differences between low and high intensity (Lamon et al., 2009; Leger et al., 2006; Mitchell et al., 2012; Ogasawara et al., 2013; Popov et al., 2006; Schoenfeld et al., 2015; Tanimoto et al., 2008; Tanimoto & Ishii, 2006). A confounding issue in the majority of these studies is that VT was not equated between groups, and the few studies that endeavoured to do so all used the VT of the high-intensity group as the standard for the low-intensity group, which resulted in lower volumes for both groups and thus potentially limited muscular adaptations. It is well established that the VT plays an important role in muscular adaptations, with evidence of a dose–response relationship between volume and hypertrophy (Schoenfeld, Ogborn, & Krieger, 2017). Thus, when different intensities of RT are performed, VT must be matched at sufficiently high levels to help ensure maximal responses for each training condition.

The present study aimed to investigate the effect of different intensities of RT across a wide spectrum of loading zones with matched VT on 1RM and muscle cross-section area (CSA) in response to 12-weeks of RT. We hypothesized that intensities between 40% and 80% 1RM would produce similar hypertrophic responses and 20% would be below the intensity threshold needed to maximize adaptations. Moreover, it was hypothesized that higher intensities (60–80% 1RM) would have greater effects on muscle strength when compared to lower intensities (20–40% 1RM) of RT.

Methods

Experimental procedures

To determine the effect of different intensities of RT on increases 1RM and CSA of the vastus lateralis (VL) and elbow flexors (EF), a within-subject design was employed in which one leg and arm was set at 20% 1RM (G20) for all participants and the contralateral limb was randomly assigned to one of the three possible conditions: 40% 1RM (G40); 60% 1RM (G60), and 80% 1RM (G80). All participants performed two sessions per week of unilateral elbow flexion (arm curl) and unilateral leg press 45° for 12 weeks. Participants performed three sets of G20 first each workout, with each set taken to volitional failure. VT (sets × repetition × load) for G20 was recorded and used to match the VT for the higher intensity condition in the contralateral limb (i.e. G40, G60, and G80). Unilateral arm curl and unilateral leg press 45° 1RM, as well as CSA of the VL and EF were assessed at pre, post-6 weeks, and post-12 weeks of training.

Subjects

Thirty health young men (age = 24.5 ± 2.4 years; height = 180.0 ± 0.7 cm; body mass = 77 ± 16.5 kg) volunteered to participate in this study. The sample was determined by a *post hoc* power analysis based on the previous research from our lab using VL CSA as the outcome measure with a target effect size difference of 0.6 and an alpha of 0.05, resulting in a power of 0.82. Participants were recreationally active with no experience in RT. All participants were made aware of the procedures, benefits and potentials risks, and then signed an informed consent document to participate in this investigation. This study was conducted according to the Declaration of Helsinki, and the Institution's Research Ethics Committee approved the experimental protocol.

Muscle CSA

Muscle CSA was determined for the EF and VL using B-mode ultrasonography with a 7.5 MHz linear-array probe (SonoAce R3, Samsung-Medison, Gangwon-do, South Korea). A researcher experienced in muscle ultrasound testing performed all measurements. To measure EF CSA, the researcher first identified the midpoint between the head of the humerus and the lateral epicondyle of the humerus, which was then marked with semipermanent ink for reference. Thereafter, the skin was transversally marked every 1 cm from the reference point along the medial and lateral aspects of the upper arm to orient ultrasound probe placement. For the VL CSA, the researcher identified the midpoint between the greater trochanter and the lateral epicondyle of the femur. The skin was then transversally marked every 2 cm from the reference point along the medial and lateral aspects of the thigh to orient probe placement.

For measures of both EF and VL, sequential ultrasound images were acquired by aligning the head of the probe with each mark on the skin following a middle-to-lateral direction. A generous amount of gel was applied to the probe to enhance conductivity and care was taken to avoid depressing the skin surface while scanning. After collecting this data, the EF and VL images were digitally reconstructed. Specifically, the images were sequentially opened in power point (Microsoft, USA), and then each image was manually rotated until the fascia of the EF and VL muscles were modelled (Lixandrão et al., 2014). CSA of the resulting EF and VL images were then measured using computerized planimetry (i.e. the VL and EF muscles CSA were contoured following the muscle fascia using an 800 dpi mouse) (Magic Mouse, Apple, USA) in two different days, 72 h apart (intra-researcher reproducibility). The planimetry software was calibrated with fixed distance scales displayed in the ultrasound images. Test–retest reliability of CSA measurements using intra-class correlation coefficient (ICC), typical error (TE), and coefficient of variation (CV) for EF were 0.99, 0.43 cm^2, and 3.2% and for vastus lateralis were 0.99, 0.59 cm^2, and 2.5%, respectively.

Maximal dynamic strength (1RM)

Unilateral elbow flexor and unilateral leg press 45° 1RM testing were performed as per American Society of Exercise Physiologists recommendations (Brown & Weir, 2001). Briefly, participants ran for 5 min on a treadmill (Movement Technology; Brudden) at 9 km h^{-1}, followed by two warm-up sets of the unilateral EF exercise and unilateral leg press 45°. In the first set, the participants performed eight repetitions with an intensity corresponding to 50% of their estimated 1RM obtained during the familiarization sessions. In the second set, they performed three repetitions with 70% of their estimated 1RM. A 3-min rest interval was afforded between warm-up sets. After the completion of the second set, participants rested for 3 min and then had up to five attempts to achieve their unilateral EF and unilateral leg press 45° 1RM. A 3-min rest interval was afforded between attempts (Brown & Weir, 2001). An experienced researcher conducted all the tests, and strong verbal encouragement was provided during the test. Test–retest reliability of 1RM measurements using ICC, TE and CV for unilateral EF were 0.99, 0.45 kg, and 1.86% and for unilateral leg press 45° were 0.99, 4.77 kg, and 2.48%, respectively.

Training programme

The RT was carried out twice per week for 12 weeks using unilateral elbow flexion and unilateral leg press 45° exercises. The study employed a within-subject design whereby one leg and arm was set at 20% 1RM (G20, $n = 30$) for all participants and the contralateral limb was randomly assigned to one of the three possible conditions: 40% 1RM (G40, $n = 10$); 60% 1RM (G60, $n = 10$), and 80% 1RM (G80, $n = 10$). The training protocol for G20 consisted of three sets of elbow flexion and leg press exercise carried out to the point of momentary concentric muscular failure (i.e. the inability to perform another concentric repetition while maintaining proper form). Total VT performed by G20 was recorded and then equated in the contralateral limb. In this case, G40, G60, and G80 groups performed how many sets and repetitions necessary to complete the VT from G20, with repetitions performed until to volitional failure and the training load was adjusted every 4 weeks to ensure the target intensity was achieved. The initial exercise performed was altered in each session; in other words, if one day, the subject started the session with the unilateral elbow flexion, the other day, he started with the unilateral leg press. All protocols were performed with a 120-s rest period between sets and cadence of repetitions was carried out with a controlled concentric and eccentric cycle of approximately 2-s each. Participants were instructed to refrain from performing any additional resistance-type training throughout the duration of the study.

Statistical analyses

Data were analysed quantitatively and visually to verify normality (Shapiro-Wilk) and existence of outliers (box-plots). For measures of reproducibility, test–retest for CSA and 1RM employed the ICC, absolute agreement, and TE which was calculated as standard deviation of the difference between day 1 and day 2 measurements/$\sqrt{2}$ and the CV which was calculated as the (TE of the difference between day 1 and day 2/means of the day 1 and day 2 values) × 100. A mixed model analysis was performed for each dependent variable (CSA and 1RM), assuming the conditions (G20, G40, G60, and G80) and time (pre, post-6 weeks and post-12 weeks) as fixed factors, and the participants as a random factor. Whenever a significant *F*-value was obtained, a *post hoc* test with a Tukey's adjustment was performed for multiple comparison. ES was calculated as the post-training mean minus the pre-training mean divided by the pooled pre-training standard deviation (Morris, 2008), where 0.2 = small, 0.5 = medium, and 0.8 = large (Cohen, 1988). In addition, we presented the mean value and confidence intervals from absolute difference between groups (CIdiff). Positive and negative confidence intervals that did not cross zero were considered significant. The significance level was set at $p < .05$, and all analyses were made with statistical software package SAS 9.2.

Results

No significant differences in any variables of interest were observed between groups at baseline. The VT for all groups was similar for unilateral elbow flexion and unilateral leg press 45° exercises throughout the study. The description of training variables is depicted in Table I.

EF and VL cross-sectional area

There was significant main effect of time in EF and VL CSA for all conditions following RT intervention ($p = .0001$). EF CSA increased significantly in all conditions from pre- to post-12 weeks (G20: 11.4% ES: 0.63, G40: 25.3% ES: 2.10, G60: 25.1% ES: 1.40, and G80: 25% ES: 1.39). When the mean value of differences between conditions were analysed at post-12 weeks, EF CSA in G80 was greater than G20 (95%CI_{diff} = 0.32 to 4.25, $F = 3.74$, d: 0.49, $p = .01$), but similar to G40 (95%CI_{diff} = −1.66 to 3.15, $F = 1.47$, d: 0.78, $p = .85$) and G60 condition (95%CI_{diff} = −1.92 to 2.88, $F = 1.47$, d: 0.78, $p = .95$) (Figure 1).

For the VL CSA, all conditions showed significant increases from pre- to post-12 weeks ($p < .0001$). VL CSA increased significantly in all conditions from pre- to post-12 weeks (G20: 8.9%, ES: 0.62; G40: 20.5%, ES: 1.16; G60: 20.4%, ES: 2.02; and G80: 19.5%, ES: 2.28). When mean value of differences between conditions were analysed post-12 weeks, VL CSA was greater in G80 than G20 (95%CI_{diff} = 0.48 to 7.21, $F = 3.09$, *d*: 0.35, $p = .01$), but similar to G40 (95%CI_{diff} = −2.97 to 5.27, $F = 1.32$, *d*: 1.55, $p = .88$) and G60 condition (95%CI_{diff} = −2.71 to 5.53, $F = 1.32$, *d*: 1.59, $p = .81$) (Figure 2).

Maximal dynamic strength (1RM)

There was a significant time × condition interaction for unilateral elbow flexion and unilateral leg press 45° 1RM ($p = .0042$). Unilateral elbow flexion 1RM increased significantly from pre- to post-6 weeks in the G20 (16.5%, ES: 0.93), G60 (30%, ES: 1.30), and G80 (31.6%, ES: 1.96) conditions ($F = 268.30$, $p \leq .05$). In addition, unilateral elbow flexion 1RM increased significantly from pre- to post-12 weeks for all conditions (G20: 23.3%, ES: 1.25; G40: 26.7%, ES: 1.33; G60: 33.6%, ES: 1.41; and G80: 54.1%, ES: 4.56) ($p < .0001$). Elbow flexion 1RM at post-12 weeks increase in G80 condition was significantly higher when compared to G20 (95%CI_{diff} = 2.35 to 10.98, $F = 11.86$, d: 1.49, $p = .001$), G40 (95%CI_{diff} = 2.31 to 12.88, $F = 11.86$, d: 1.69, $p = .001$), and G60 conditions (95%CI_{diff} = 1.51 to 12.08, $F = 11.86$, d: 1.32, $p = .001$) (Table II).

Unilateral leg press 45° 1RM increased significantly from pre- to post-6 weeks in G20 (15.8, ES: 0.75), G40 (27.9%, ES: 1.24), G60 (32.1%, ES: 1.42), and G80 (25.6%, ES: 1.42) conditions ($F = 242.40$; $p < .0001$). Additionally, unilateral leg press 45° 1RM increased significantly from pre- to post-12 weeks for all conditions (G20: 22.1% ES: 1.14; G40: 30.4%, ES: 1.43; G60: 55.4%, ES: 2.99; and G80: 45.7%, ES: 3.27) ($p < .0001$). Finally, leg press 45° 1RM increases at post-12 weeks in the G60 and G80 conditions were significantly higher when compared to G20 and G40 (G60 vs. G20: 95%CI_{diff} = −0.65 to 73.66, $F = 10.82$, d: 1.00, $p = .04$; G80 vs. G20: 95%CI_{diff} = 3.34 to 77.66, $F = 10.82$, d: 1.11, $p < .05$; G60 vs. G40: 95%CI_{diff} = −4.37 to 3.87, $F = 10.82$, d: 1.59, $p = .02$; and G80 vs. G40: 95%CI_{diff} = 8.49 to 99.51, $F = 10.82$, d: 1.74, $p < .05$) (Table II).

Discussion

The present study investigated the effects of different intensities of RT (20–80% 1RM) with equated

Table I. Training variables for the unilateral elbow flexion and unilateral leg press 45° exercises.

Unilateral elbow flexion				
Training variables	G20	G40	G60	G80
Sets	3 ± 0	3.7 ± 1	4.5 ± 1.2	4.2 ± 1
Repetitions	67.7 ± 18.7*	28.2 ± 10.5**	14.5 ± 4.7	10.2 ± 2.8
Volume load	21,674.1 ± 2952.7	21,919.1 ± 3028.1	20,822 ± 3644.1	20,543 ± 3479.5
Unilateral leg press 45°				
Training variables	G20	G40	G60	G80
Sets	3 ± 0	2.5 ± 0.4	3.4 ± 1.4	3.1 ± 0.9
Repetitions	61.1 ± 29.9*	30.8 ± 8.0	18.8 ± 5.9	14.0 ± 4.6
Volume load	163,043.0 ± 34,695.2	153,946.2 ± 28,285.5	160,900 ± 30,997.9	169,095.4 ± 36,054.5

*Significant difference from G40, G60 and G80 ($p < .05$).
**Significant difference from G80 ($p < .05$).

volume on muscular strength and hypertrophy following 12 weeks of regimented training. Our main findings were: (a) all intensities of RT increased the EF and VL CSA; (b) all intensities of RT increased elbow flexion and leg press 1RM. The magnitude of increases in muscle CSA and 1RM of the upper and lower body when training at 80% 1RM were greater than at 20% 1RM.

The findings of this study call into question the American College of Sports Medicine guidelines stating that the use of loads ≥65% 1RM are required to promote hypertrophic adaptations (American College of Sports Medicine, 2009). Alternatively, our findings corroborate the results from other studies that demonstrated low-intensity RT performed until volitional failure can increase muscle mass to a similar extent as high-intensity RT at least with loads ≥40% 1RM, even when volume is equated between conditions (Mitchell et al., 2012; Ogasawara et al., 2013; Schoenfeld et al., 2015). Some researchers have proposed that it is necessary to perform a higher volume of low-intensity training to achieve the magnitude of increase in muscle size observed with high-intensity training (Burd et al., 2010; Burd, Mitchell, Churchward-Venne, & Phillips, 2012; Mitchell et al., 2012). In general, a majority of studies that investigated the topic employed a substantially higher training volume for the low-intensity condition (Mitchell et al., 2012; Ogasawara et al., 2013; Schoenfeld et al., 2015), which conceivably could have affected the hypertrophic response.

Ours is the first study to match the VT between a wide range of intensities (e.g. 20–80% 1RM) based on VT in the lowest intensity condition. This strategy was adopted in order to avoid potentially misleading interpretations when the VT between training protocols are different and thus isolate the effects of intensity on muscular adaptations. For example, the VT performed in other studies that use low-intensity RT (30% 1RM) was higher than those shown with high-intensity RT (80% 1RM) (Mitchell et al., 2012; Ogasawara et al., 2013; Schoenfeld et al., 2015). It is possible that muscle hypertrophy in the heavier intensity conditions in these studies may have been blunted by the lower amount of volume performed compared to the lighter-intensity conditions. However, our study indicates that volume was not a significant factor in this regard, at least with respect to intensities of ≥40% 1RM. This suggests that there is a threshold of volume needed to promote marked increases in muscle hypertrophy with intensities between 40% and 80% 1RM.

Although upper and lower body CSA were increased in all conditions, the highest intensity condition (80% 1RM) presented greater gains compared with the lightest intensity condition (20% 1RM). Consistent with these findings, data from Holm et al. (2008) found a higher increase in quadriceps CSA when training at 70% vs. 15.5% 1RM with the VT equated between the conditions. However, subjects in the study did not train to failure in the low-intensity condition, confounding the ability to draw causality on the hypertrophic effects of the different loading schemes. Our findings suggest that there is a minimum intensity necessary to trigger important mechanisms involved in increasing muscle size (Holm et al., 2008; Kumar et al., 2009), and it appears that 20% 1RM falls below this threshold. Given that we did not study intensities between 20% and 40% 1RM, it is not clear where the minimum threshold lies along this continuum.

Hypertrophy-oriented routines are often designed to raise mechanical tension and/or metabolic stress (Goto, Ishii, Kizuka, & Takamatsu, 2005; Schoenfeld, 2010; Seynnes, de Boer, & Narici, 2007). Given that the increase in CSA in this study was similar between intensities of 40% and 80%, it can be inferred that protocols designed to maximize metabolic stress (i.e. high number of repetitions and low to moderate intensities) and protocols designed to maximize mechanical tension (low number of

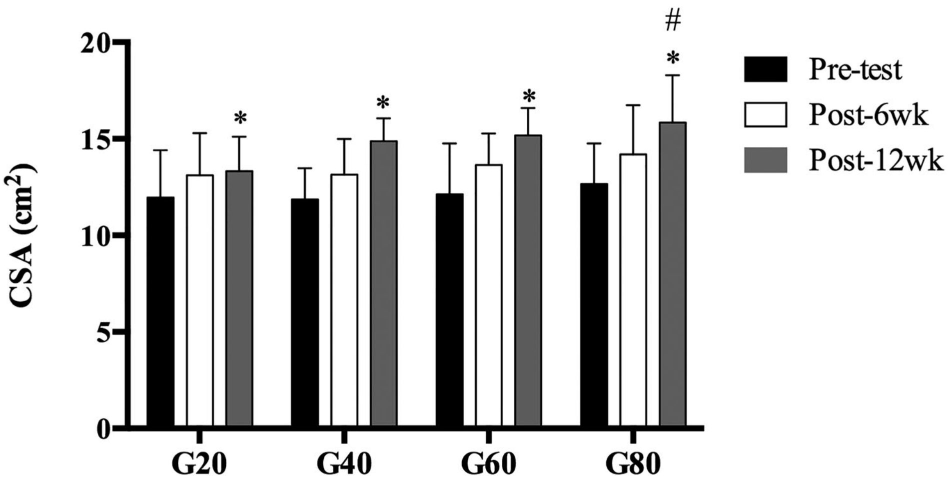

Figure 1. Elbow flexor CSA values from pre-test to post-6 weeks and post-12 weeks for G20, G40, G60, and G80 conditions (mean ± SD). *Significant difference from pre-test ($p < .05$). #Significantly greater than G20 group at post-12 weeks ($p < .05$).

repetitions and high intensities) would promote similar hypertrophic increases when the VT is matched. Thus, these findings suggest that VT plays an important role in increasing muscle mass as opposed to inherent aspects of the protocol itself or training stimulus.

There were significant increases in strength for all groups following 6 and 12 weeks of RT. The increases in strength levels in the initial weeks of training have been attributed to neural mechanisms (Gabriel, Kamen, & Frost, 2006; Sale, 1988), and this appears to be the case even with the very low-intensity condition (20% 1RM) employed in our study. Holm et al. (2008) found that an intensity of 15.5% 1RM was insufficient for increasing muscle strength following regimented RT. However, as previously mentioned, the sets in this condition were not taken to muscular failure. In contrast to the findings by Holm et al. (2008), our results showed G20 increased 1RM in the arm curl and leg press throughout the training period. Discrepancies in results may in part be attributable to differences in the manipulation of total training volume in combination with the level of effort expended (i.e. proximity to failure) in the low-intensity condition. Specifically, the total VT for all groups in our study was based on G20 and all the volume of all other conditions (G40, G60, and G80) was matched to the volume load achieved in G20, with repetitions performed until to volitional failure.

One interesting aspect of our findings is that strength appeared to plateau after 6 weeks in the lower intensity conditions and, after 12 weeks, higher training intensities resulted in greater strength increases compared to lower intensities. These results are in agreement with previous studies on the topic that demonstrated an advantage for higher intensities on muscle strength performance (Campos et al.,

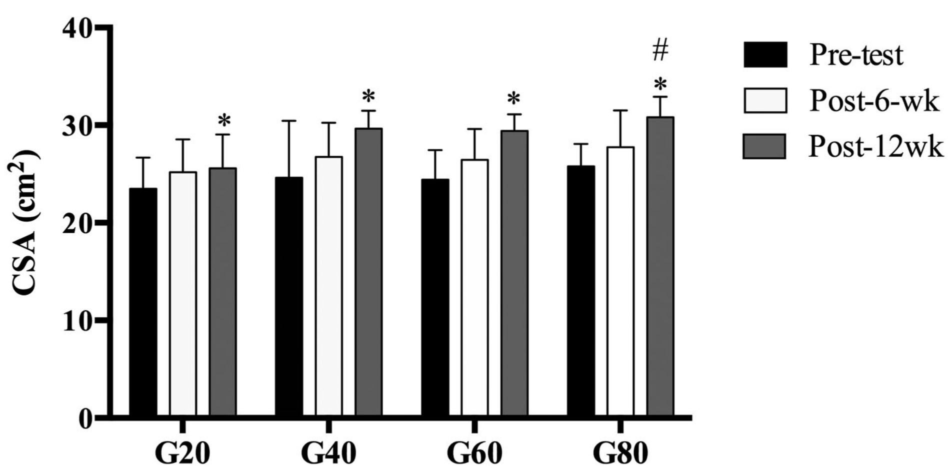

Figure 2. VL CSA values from pre-test to post-6 weeks and post-12 weeks for G20, G40, G60, and G80 conditions (mean ± SD). *Significant difference from pre-test ($p < .05$). #Significantly greater than G20 group at post-12 weeks ($p < .05$).

Table II. Unilateral leg press 45° and unilateral EF maximum dynamic strength (1RM kg, mean ± SD) for G20, G40, G60, and 680 conditions, pre-test, post-6 week, and post-12 week interventions.

	Unilateral leg press 45° 1RM (kg)			EF 1RM (kg)		
	Pre-test	Post-6 week	Post-12 week	Pre-test	Post-6 week	Post-12 week
G20	204.3 ± 39.0	236.6 ± 46.4*	249.5 ± 39.7*	24.6 ± 4.1	28.6 ± 4.5*	30.3 ± 4.9*
G40	181.0 ± 38.7	231.5 ± 42.7*	236.0 ± 37.9*	23.2 ± 4.2	28.1 ± 4.3	29.4 ± 5.0*
G60	184.0 ± 42.2	243.0 ± 40.6*	286.0 ± 23.2*, **	22.6 ± 4.9	29.4 ± 5.5*	30.2 ± 5.8*
G80	199.0 ± 32.4	250.0 ± 38.8*	290.0 ± 22.1*, **	24.0 ± 3.4	31.6 ± 4.3*	37.0 ± 2.2*, ***

*Significant difference from pre-test ($p < .05$).
**Significantly greater than G20 and G40 groups at post-12 weeks.
***Significantly greater than G20 and G40 and G60 groups at post-12 weeks ($p < .05$).

2002; Mitchell et al., 2012; Ogasawara et al., 2013; Schoenfeld et al., 2015). Untrained individuals participating in the initial stages of RT generally have a low level of fitness and lack the coordination to perform exercises in a fluid manner. Thus, all loading schemes provided a sufficient stimulus to produce increases in muscular strength (Harris, Debeliso, Spitzer-gibson, & Adams, 2004). However, it can be speculated that over time heavier intensities are necessary to continue making gains. This is consistent with evidence that resistance-trained individuals require higher intensities to improve muscle strength (Peterson, Rhea, & Alvar, 2004; Rhea, Alvar, Burkett, & Ball, 2003).

Although we did not attempt to elucidate the mechanisms responsible for our findings, it seems plausible that neural adaptations may explain the different strength responses between intensities. Specifically, high-intensity RT may promote greater effects on motor unit recruitment, motor unit firing rates, and/or alterations in agonist-antagonist co-activation ratios compared to training at lower intensities (Gabriel et al., 2006; Sale, 1988). Alternatively, other factors related to the principle of specificity may be involved in the process, whereby high-intensity training has greater similarities to 1RM testing versus low-intensity training (Aagaard, Simonsen, Trolle, Bangsbo, & Klausen, 1996; Cronin, McNair, & Marshall, 2001). Further research is needed to determine mechanistic explanations.

The present study is not without limitations. First, the study was performed in young men with no previous experience in RT. Thus, our findings cannot be generalized to other population including women, elderly, and/or resistance-trained individuals. Second, it is possible that differences in training status, hormonal influence, and other factors could influence muscular adaptations when training at different intensities. Third, we cannot rule out the possibility that the cross-education effect may have influenced strength results given the within-subject design. However, the fact that the highest intensity condition showed the greatest changes in strength indicates that any influence of cross-education, if such a phenomenon did in fact occur, was not sufficient to counteract the effects of heavier loading on this outcome. Lastly, we did not attempt to determine nutritional intake, which may have influenced results between conditions. However, the within-subject design would have helped to minimize any potential variations attributed to this variable.

In conclusion, our results demonstrated that intensities ranging from 20% to 80% 1RM are effective for increasing muscle strength and hypertrophy in men with no experience in RT. However, our findings indicate that the lowest RT intensity (20% 1RM) was suboptimal for maximizing muscular adaptations. With regards to strength gains, our results indicate that over the initial 6 weeks of training all the studied intensities can produce increases in 1RM. However, if maximizing strength gains over the long-term training is a primary goal, it is necessary employ higher training intensities.

Disclosure statement

No potential conflict of interest was reported by the authors.

ORCID

Hamilton Roschel http://orcid.org/0000-0002-9513-6132
Lucas Duarte Tavares http://orcid.org/0000-0003-0941-6224

References

Aagaard, P., Simonsen, E. B., Trolle, M., Bangsbo, J., & Klausen, K. (1996). Specificity of training velocity and training load on gains in isokinetic knee joint strength. *Acta Physiologica Scandinavica*, *156*(2), 123–129.

American College of Sports Medicine. (2009). American College of Sports Medicine position stand. Progression models in resistance training for healthy adults. *Medicine & Science in Sports & Exercise*, *41*(3), 687–708. doi:10.1249/MSS.0b013e3181915670

Brown, L. E., & Weir, J. P. (2001). Accurate assessment of muscular strength and power, ASEP procedures recommendation. *Journal of Exercise Physiology*, *4*(3), 1–21.

Burd, N. A., Mitchell, C. J., Churchward-Venne, T. A., & Phillips, S. M. (2012). Bigger weights may not beget bigger muscles: Evidence from acute muscle protein synthetic responses after resistance exercise. *Applied Physiology, Nutrition, and Metabolism*, *37*(3), 551–554.

Burd, N. A., West, D. W. D., Staples, A. W., Atherton, P. J., Baker, J. M., Moore, D. R., … Baker, S. K. (2010). Low-load high volume resistance exercise stimulates muscle protein synthesis more than high-load low volume resistance exercise in young men. *PloS One*, *5*(8), e12033.

Campos, G. E., Luecke, T. J., Wendeln, H. K., Toma, K., Hagerman, F. C., Murray, T. F., … Staron, R. S. (2002). Muscular adaptations in response to three different resistance-training regimens: Specificity of repetition maximum training zones. *European Journal of Applied Physiology*, *88*(1–2), 50–60. doi:10.1007/s00421-002-0681-6

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences*. Hillsdale, NJ: Lawrence Earlbaum Associates. 2.

Cronin, J., McNair, P. J., & Marshall, R. N. (2001). Velocity specificity, combination training and sport specific tasks. *Journal of Science and Medicine in Sport*, *4*(2), 168–178.

FitzGerald, S. J., Barlow, C. E., Kampert, J. B., Morrow, J. R., Jr, Jackson, A. W., & Blair, S. N. (2004). Muscular fitness and all-cause mortality: Prospective observations. *Journal of Physical Activity and Health*, *1*(1), 7–18.

Gabriel, D. A., Kamen, G., & Frost, G. (2006). Neural adaptations to resistive exercise. *Sports Medicine*, *36*(2), 133–149.

Goto, K., Ishii, N., Kizuka, T., & Takamatsu, K. (2005). The impact of metabolic stress on hormonal responses and muscular adaptations. *Medicine & Science in Sports & Exercise*, *37*(6), 955–963.

Harris, C., Debeliso, M. A., Spitzer-gibson, T. A., & Adams, K. J. (2004). The effect of resistance-training intensity on strength-gain response in the older adult. *The Journal of Strength & Conditioning Research*, *18*(4), 833–838.

Holm, L., Reitelseder, S., Pedersen, T. G., Doessing, S., Petersen, S. G., Flyvbjerg, A., … Kjaer, M. (2008). Changes in muscle size and MHC composition in response to resistance exercise with heavy and light loading intensity. *Journal of Applied Physiology*, *105*(5), 1454–1461.

Kumar, V., Selby, A., Rankin, D., Patel, R., Atherton, P., Hildebrandt, W., … Rennie, M. J. (2009). Age-related differences in the dose-response relationship of muscle protein synthesis to resistance exercise in young and old men. *The Journal of Physiology*, *587*(Pt 1), 211–217. doi:10.1113/jphysiol.2008.164483

Lamon, S., Wallace, M. A., Leger, B., & Russell, A. P. (2009). Regulation of STARS and its downstream targets suggest a novel pathway involved in human skeletal muscle hypertrophy and atrophy. *The Journal of Physiology*, *587*(Pt 8), 1795–1803. doi:10.1113/jphysiol.2009.168674

Leger, B., Cartoni, R., Praz, M., Lamon, S., Deriaz, O., Crettenand, A., … Russell, A. P. (2006). Akt signalling through GSK-3beta, mTOR and Foxo1 is involved in human skeletal muscle hypertrophy and atrophy. *The Journal of Physiology*, *576*(Pt 3), 923–933. doi:10.1113/jphysiol.2006.116715

Lixandrão, M. E., Ugrinowitsch, C., Bottaro, M., Chacon-Mikahil, M. P. T., Cavaglieri, C. R., Min, L. L., … Libardi, C. A. (2014). Vastus lateralis muscle cross-sectional area ultrasonography validity for image fitting in humans. *The Journal of Strength & Conditioning Research*, *28*(11), 3293–3297.

Los Arcos, A., Yanci, J., Mendiguchia, J., Salinero, J. J., Brughelli, M., & Castagna, C. (2014). Short-term training effects of vertically and horizontally oriented exercises on neuromuscular performance in professional soccer players. *International Journal of Sports Physiology and Performance*, *9*(3), 480–488.

Markovic, G., Jukic, I., Milanovic, D., & Metikos, D. (2007). Effects of sprint and plyometric training on muscle function and athletic performance. *The Journal of Strength & Conditioning Research*, *21*(2), 543–549.

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. doi:10.1152/japplphysiol.00307.2012

Morris, S. B. (2008). Estimating effect sizes from pretest-posttest-control group designs. *Organizational Research Methods*, *11*(2), 364–386. doi:10.1177/1094428106291059

Ogasawara, R., Loenneke, J. P., Thiebaud, R. S., & Abe, T. (2013). Low-Load bench press training to fatigue results in muscle hypertrophy similar to high-load bench press training. *International Journal of Clinical Medicine*, *4*(2), 114–121.

Pareja-Blanco, F., Rodríguez-Rosell, D., Sánchez-Medina, L., Gorostiaga, E. M., & González-Badillo, J. J. (2014). Effect of movement velocity during resistance training on neuromuscular performance. *International Journal of Sports Medicine*, *35*(11), 916–924.

Peterson, M. D., Rhea, M. R., & Alvar, B. A. (2004). Maximizing strength development in athletes: A meta-analysis to determine the dose-response relationship. *The Journal of Strength & Conditioning Research*, *18*(2), 377–382.

Popov, D. V., Swirkun, D. V., Netreba, A. I., Tarasova, O. S., Prostova, A. B., Larina, I. M., … Vinogradova, O. L. (2006). Hormonal adaptation determines the increase in muscle mass and strength during low-intensity strength training without relaxation. *Human Physiology*, *32*(5), 609–614.

Rantanen, T., Avlund, K., Suominen, H., Schroll, M., Frändin, K., & Pertti, E. (2002). Muscle strength as a predictor of onset of ADL dependence in people aged 75 years. *Aging Clinical and Experimental Research*, *14*(3 Suppl.), 10–15.

Rhea, M. R., Alvar, B. A., Burkett, L. N., & Ball, S. D. (2003). A meta-analysis to determine the dose response for strength development. *Medicine and Science in Sports and Exercise*, *35*(3), 456–464.

Sale, D. G. (1988). Neural adaptation to resistance training. *Medicine and Science in Sports and Exercise*, *20*(5 Suppl.), S135–45.

Schoenfeld, B. J. (2010). The mechanisms of muscle hypertrophy and their application to resistance training. *The Journal of Strength & Conditioning Research*, *24*(10), 2857–2872.

Schoenfeld, B. J., Contreras, B., Willardson, J. M., Fontana, F., & Tiryaki-Sonmez, G. (2014). Muscle activation during low-versus high-load resistance training in well-trained men. *European Journal of Applied Physiology*, *114*(12), 2491–2497.

Schoenfeld, B. J., Grgic, J., Ogborn, D., & Krieger, J. W. (2017). Strength and hypertrophy adaptations between low- versus high-load resistance training: A systematic review and meta-analysis. *Journal of Strength and Conditioning Research*. doi:10.1519/JSC.0000000000002200

Schoenfeld, B. J., Ogborn, D., & Krieger, J. W. (2017). Dose-response relationship between weekly resistance training volume and increases in muscle mass: A systematic review and meta-analysis. *Journal of Sports Sciences*, *35*(11), 1073–1082.

Schoenfeld, B. J., Peterson, M. D., Ogborn, D., Contreras, B., & Sonmez, G. T. (2015). Effects of Low-versus high-load resistance training on muscle strength and hypertrophy in well-trained Men. *Journal of Strength and Conditioning Research/National Strength & Conditioning Association*, *29*(10), 2954–2963.

Schuenke, M. D., Herman, J. R., Gliders, R. M., Hagerman, F. C., Hikida, R. S., Rana, S. R., … Staron, R. S. (2012). Early-phase muscular adaptations in response to slow-speed versus traditional resistance-training regimens. *European Journal of Applied Physiology*, *112*(10), 3585–3595.

Seynnes, O. R., de Boer, M., & Narici, M. V. (2007). Early skeletal muscle hypertrophy and architectural changes in response to high-intensity resistance training. *Journal of Applied Physiology*, *102*(1), 368–373.

Tanimoto, M., & Ishii, N. (2006). Effects of low-intensity resistance exercise with slow movement and tonic force generation on muscular function in young men. *Journal of Applied Physiology*, *100*(4), 1150–1157. doi:10.1152/japplphysiol.00741.2005

Tanimoto, M., Sanada, K., Yamamoto, K., Kawano, H., Gando, Y., Tabata, I., … Miyachi, M. (2008). Effects of whole-body low-intensity resistance training with slow movement and tonic force generation on muscular size and strength in young men. *Journal of Strength and Conditioning Research*, *22*(6), 1926–1938. doi:10.1519/JSC.0b013e318185f2b0