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Comparing the effects of low and high load resistance exercise to failure on adaptive responses to resistance exercise in young women

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Abstract

The aim of this study was to compare the effect of 6 weeks of resistance training to volitional failure at low (30% 1 repetition maximum (RM)) or high (80%1RM) loads on gains in muscle size and strength in young women. Thirteen women (age: 29.7 ± 4.7years; height 166.7 ± 6.4cm; weight 64.2 ± 12.2kg) completed 2 training sessions per week for 6 weeks and muscle strength (1RM), muscle thickness (ultrasound) were measured before and after training. Training comprised 1 set to volitional failure of unilateral leg extensions and bicep curls with each limb randomly assigned to train at either 80% 1RM or 30% 1RM. Increases in muscle thickness [arms: 6.81 ± 3.15% (30% 1RM), 5.90 ± 3.13% (80% 1RM) and legs: 9.37 ± 5.61% (30% 1RM), 9.13 ± 7.9% (80% 1RM)] and strength [arms: 15.4 ± 12.2% (30% 1RM), 18.26 ± 12.2% (80% 1RM) and legs: 25.30 ± 18.4 (30% 1RM), 27.20 ± 14.5 (80% 1RM)] were not different between loads. When resistance exercise is performed to volitional failure gains in muscle size and strength are independent of load in young women.

Keywords: Exercise, muscle, load, women, hypertrophy

Introduction

Skeletal muscle has an often underappreciated role in health (Wolfe, 2006) and low muscle strength has been linked with increased risk of poor health outcomes (Celis-Morales et al., 2018). From a functional point of view muscle mass and strength has broad importance ranging from sporting performance in athletic populations to performing activities of daily living in older populations (Hairi et al., 2010). It is, therefore, not surprising that the current physical activity recommendations include advice for adults to perform muscle strengthening activities 2 days per week (WHO, 2011). When recommending resistance exercise training there are many variables, such as the number of sets, repetitions and load, which must be considered. The American College of Sports Medicine (ACSM) recommend that for novice lifters resistance training 2-3 days per week with 1-3 sets of 8-12 repetitions with a training load of 60-85% one-repetition maximum (1RM) promotes muscular hypertrophy and can maximize strength (Ratamess et al., 2009).

The strength of the evidence in support of these studies has, however, been challenged by several researchers (Carpinelli, 2008; J. Fisher, Steele, Bruce-Low, & Smith, 2011; J. Fisher, Steele, & Smith, 2017). Indeed it has been demonstrated, in men, recently that if exercise is performed to volitional failure then gains in muscle mass and strength, although data are less clear on this, are similar regardless of the load at which exercise is performed (J. P. Fisher & Steele, 2017; Cameron J Mitchell et al., 2012; Morton et al., 2016; Schoenfeld, Peterson, Ogborn, Contreras, & Sonmez, 2015). The theory underlying these observations is that when performed to failure, regardless of load, larger motor units will have been recruited in an attempt to maintain force production – as predicted by the size principle (De Luca & Contessa, 2012; Henneman, 1985). This is not the case when making comparisons between different training loads when matched for training volume (load * number of repetitions) as a greater volume is required to reach failure at lower loads. In fact, as would be expected in such studies gains in muscle size and strength are greater when training is performed at higher loads (e.g. Holm et al., 2008).

These previous studies which have compared low and high load resistance exercise training to volitional failure have all, to our knowledge, been performed in men and whether similar observations are seen in women remains to be established. This is a major issue in sports and exercise science research with women general underrepresented in such research (Costello, Bieuzen, & Bleakley, 2014). As men and women have been found to respond differently to training programmes that involve fatiguing contractions, with women being less fatigable in a task dependent manner (Gentil et al., 2017; Hill, Housh, Smith, Schmidt, & Johnson, 2018; Hunter, 2016; Stuart, Steele, Gentil, Giessing, & Fisher, 2018) there is potential for a different response, comparing low and high load exercise to volitional failure ,in women . . An understanding of whether similar responses are seen in women is of clear importance as resistance exercise recommendations are independent of sex. The aim of the current study, therefore, is to compare the effect of 6 weeks of resistance training to volitional failure at low (30% 1RM) or high (80%1RM) load on gains in muscle size and strength in young women.

Materials and methods

Participants

Thirteen women (age: 29.7 ± 4.7years; height 166.7 ± 6.4cm; weight 64.2 ± 12.2kg; body fat 24.9 ± 9.2%) volunteered to participate in the current study. Participants were not engaging in more than 2 hours per week of moderate/high intensity aerobic exercise or any resistance training and were normotensive, free from injury, metabolic or cardiovascular disease. The study was approved by the Local Ethics Committee and adhered to the declaration of Helsinki. Prior to testing, participants received written and verbal instructions regarding the nature of the investigation, completed a health-screening questionnaire (PAR-Q+) and provided written informed consent.

Study protocol

A randomized, within-subject design was employed in this study. Participants completed 6 weeks of resistance training (knee extensions and biceps curls) with 2 sessions per week. Each session involved a single set of each exercise to volitional failure. Upon entry to the study the participants left and right legs were randomised to perform knee extensor exercise at either 30%1RM or 80%1RM. This order was switched for the upper body. For example a participant with right leg randomised to 80%1RM and left leg to 30%1RM would have the right arm train at 80%1RM and left arm at 30%1RM. Baseline measurements were completed 3-4 days before the start of the training and included; body composition via air displacement plethysmography (BodPod), vastus lateralis (VL) and biceps brachii (BB) muscle thickness (MT) via ultrasound, knee extensor and elbow flexor strength via 1RM. 1RM being also measured on week 3 to re-adjust the training load. The training protocol ended once each subject completed a total of 6 weeks of training. Post-training measurements were taken 3-4 days after the end of training meaning participants were at approximately the same stage of menstrual cycle for baseline and post-training measurements. Measurements were also taken at the same time of the day by the same investigator. The participants were asked to refrain from any other resistance exercise training for the duration of the study and to maintain normal physical activity and nutrition habits.

Procedures

Muscle thickness: Muscle thickness was assessed non-invasively via ultrasound at baseline and post-training. Ultrasound is a valid, reliable and low-cost method used to assess changes in muscular thickness and cross-sectional area (Franchi et al., 2018). Transverse images were taken bilaterally for the biceps brachii and vastus lateralis muscles using a using a portable brightness mode (B-mode) ultrasound-imaging device (Echoblaster 128 Ext, Telemed Ltd®, Lithuania) with an 7.5Hz linear array transducer. Prior to image collection, anatomical locations were identified and marked with a pen. For the biceps brachii, images were taken at 30% of the distance between the lateral epicondyle of the humerus and the acromion process of the scapula. For the vastus lateralis, measurements were taken 70% of the distance between the lateral condyle of the femur and greater trochanter. Great care was taken to ensure the same limb positioning and consistent, minimal pressure, limiting compression of the muscle. In addition, to increase acoustic coupling and minimize near field artefacts, a water-soluble transmission gel was applied to the skin. All ultrasound images were digitized and analyzed with ImageJ software ver. 1.37. Muscle thickness was measured from the subcutaneous adipose tissue-muscle interface to the muscle-bone interface. All measurements were made by the same investigator pre- and post-intervention to ensure reproducibility (Intra-operator coefficient of variation: 4.4%).

Muscle strength: After familiarisation with the 1RM procedure, muscle strength was quantified at baseline, week 3 and post-intervention, via measurement of 1RM which has been shown to be a valid measure of muscle strength (Verdijk, van Loon, Meijer, & Savelberg, 2009). Measurement of 1RM was carried out unilaterally on a training machine (M2 Inspire Fitness ®, Corona, CA, USA) for leg extension, with increments of 4.5kg and a range of motion from 90° to near full extension, or using dumbbells for bicep curls, with 0.25kg increments and a range of motion from 100° to near full flexion. The highest load successfully lifted with proper technique through the entire range of motion was recorded as 1RM.

Resistance exercise training: During all training sessions, subjects completed unilateral dumbbell bicep curls and unilateral leg extensions on an M2 machine (Inspire Fitness ®, Corona, CA, USA). The loads used for each limb corresponded to either 30% or 80% 1RM, as described previously. Participants were instructed to perform the concentric and eccentric phases for approximately 1 s each. Participants were verbally encouraged during each set. Voluntary failure was defined as the inability to perform one repetition at its full range of motion. Training volume was calculated as the number of repetitions multiplied by the training load. All training sessions were supervised by the same investigator and attendance at sessions was 100%.

Statistical analyses: Data are reported as mean ± standard deviation (SD) unless otherwise stated. The normality and homogeneity for outcome measures were tested using the Shapiro–Wilk's and Levene's tests, respectively. Training volume, muscle thickness and muscle strength were compared, with arms and legs treaded individually, by a two-way (time × group [30% 1RM vs. 80% 1RM]) repeated measures analyses of variance (ANOVA). Where significant interaction effects were observed Bonferroni post-hoc t-tests were used to compare between groups at each time point. Statistical significance was set a priori at $p \leq 0.05$. GraphPad Prism software was used for all statistical analyses.

Results

Training volume

Training volume data for both arms and legs is visualised in figure 1. For the knee extensor muscles the ANOVA revealed a main effect of time ($F_{5,120}$=9.74, p<0.01) and group ($F_{1,120}$=13.67, p=0<01) and an interaction effect ($F_{5,120}$=3.07, p=0.01). Post-hoc analysis revealed a higher training volume at 30% 1RM in weeks 4 (difference 378 kg, 95%CI[-668 to -89kg], p<0.01), 5 (difference 491 kg, 95%CI[-780 to -203kg], p<0.01) and 6 (difference 409 kg, 95%CI[-698 to -120kg], p<0.01). For the elbow flexors the ANOVA revealed a main effect of time ($F_{5,120}$=2.85, p=0.02) and group ($F_{1,120}$=20.44, p<0.01) effects but no interaction effect was observed ($F_{5,120}$=1.09, p=0.37). Post-hoc analysis revealed a higher training volume at 30% 1RM during all weeks: 1 (difference 102 kg, 95%CI[-184 to -20kg], p<0.01), 2 (difference 88 kg, 95%CI[-170 to -6kg], p<0.01), 3 (difference 120 kg, 95%CI[-202 to -38kg], p<0.01), 4 (difference 139 kg, 95%CI[-221 to -57kg], p<0.01), 5 (difference 121 kg, 95%CI[-203 to -39kg], p<0.01) and 6 (difference 131 kg, 95%CI[-213 to -50kg], p<0.01).

Muscle thickness

Muscle thickness data for both arms and legs is visualised in figure 2. For the vastus lateralis there was a main effect of time ($F_{1,24}$=60.75, p<0.01) but no group ($F_{1,24}$=0.01, p=0.93) or interaction ($F_{1,24}$=0.02, p=0.88) effects. The increase at 30% 1RM was 9.4 ± 5.6% and at 80% 1RM was 9.3 ± 7.9%. Similarly, with the biceps brachii an effect of time ($F_{1,24}$=109.17, p<0.01) was observed with no group ($F_{1,24}$=0.03, p=0.87) or interaction ($F_{1,24}$=0.53, p=0.47) effects. The increase at 30% 1RM was 6.8 ± 3.2% and at 80% 1RM was 5.9 ± 3.1%.

Muscle strength

Muscle strength data for both arms and legs is visualised in figure 3. For the knee extensors there was a main effect of time ($F_{1,24}$=59.12, p<0.01) but no group ($F_{1,24}$=0.09, p=0.77) or interaction ($F_{1,24}$=0.20, p=0.66) effects. The increase at 30% 1RM was 25.3 ± 18.4% and at 80% 1RM was 27.2 ± 14.5%. Similarly, with the elbow flexors an effect of time ($F_{1,24}$=40.41, p<0.01) was observed with no group ($F_{1,24}$=0.10, p=0.75) or interaction ($F_{1,24}$=0.30, p=0.589) effects. The increase at 30% 1RM was 15.4 ± 12.2% and at 80% 1RM was 18.3 ± 12.2%.

Discussion

The current study has demonstrated that increases in muscle size and strength are the same, at 30 or 80% of 1RM, to after 6 weeks of resistance training, 1 set to volitional failure, in young women. As is the case in the majority of sports and exercise science (Costello et al., 2014) there was previously a dearth of studies investigating muscular adaptations to resistance exercise training to volitional failure in women. This is the first study, therefore, to show this in women and agrees with the previously published studies in men (J. P. Fisher & Steele, 2017; Cameron J Mitchell et al., 2012; Morton et al., 2016; Schoenfeld et al., 2015). It is worth pointing out that whilst all the studies in men are in agreement that hypertrophy does not differ, when comparing low and high load resistance training to volitional failure, there is not absolute agreement when it comes to strength gains. Whilst some have found strength gains to be similar between different loads (J. P. Fisher & Steele, 2017) others have found some evidence that strength gains are higher with higher, versus lower loads (Cameron J Mitchell et al., 2012; Morton et al., 2016; Schoenfeld et al., 2015). It is worth pointing out that in these studies significantly greater strength increases, at higher loads, were only seen with some, but not all, strength measures made making firm conclusions on this not straightforward. Further long term studies with large sample sizes including both men and women are needed to investigate this further. But, to note again, there was no evidence of differences in strength gains in women between the different training loads in the current study.

As well as highlighting the lack of effect of exercise load the current study also demonstrates that when performed to fatigue the volume of training (load x repetitions) does not mediate the efficacy of training. As with studies in men we have found that, as expected, the training volume was significantly higher at 30% 1RM when compared to 80% 1RM, but the increases in muscle size and strength were the same.

Together this body of work would indicate that the current resistance exercise recommendations, for both men and women, require to be changed to highlight that as long as exercising to volitional failure the load at which exercise are performed will not mediate gains in muscle size and strength. These recommendations can, therefore, be simple and offer more flexibility and allow individuals to exercise in a way that is most enjoyable for them and thus something they are more likely to maintain in the long term. Whilst we did not compare enjoyment of training at the different loads others have investigated this and found that low, compared to high, loads resulted in greater discomfort as well as an increase in time,a major barrier to exercise participation (Trost, Owen, Bauman, Sallis, & Brown, 2002), taken to complete (J. P. Fisher & Steele, 2017). This may mean that individuals select higher load training, similar to the current recommendations, but would give freedom of choice which early work has indicated may be a useful way to prescribe resistance exercise training (Elsangedy et al., 2018). Further long term work investigating adherence and long term outcomes of resistance training at different loads are required.

Based on the size principle motor units, and the muscle fibres they innervate, are recruited progressively based on the force requirements. That is, the smaller, lower threshold motor units that innervate type 1 fibres are recruited first followed by higher threshold motor units, that innervate type 2 fibres (Henneman, 1985). For this reason many studies have hypothesised that to maximise gains in muscle mass and strength heavier loads are required to ensure activation, fatigue and thus hypertrophy of all muscle fibres (Jenkins et al., 2015; Schoenfeld, Contreras, Willardson, Fontana, & Tiryaki-Sonmez, 2014). However, the data generated which purportedly supports this hypothesis is based on the use of surface electromyography (sEMG) data to show a greater muscle activation when lifting heavier loads (Jenkins et al., 2015; Schoenfeld et al., 2014). Interpretation of such data is not straight forward and it cannot be assumed that a higher sEMG amplitude, whilst lifting heavier loads, can be attributed to the recruitment of the complete pool of motor units. The current study and the work of others, in men, indicate that (C. J. Mitchell et al., 2012; Morton et al., 2016) whilst, larger motor units may be recruited at heavier loads, when performed to failure a similar level of motor unit activation and thus adaptation occurs regardless of load (Carpinelli, 2008; J. Fisher et al., 2011). Further work is, however, required to confirm the mechanisms underlying these observations.

Although the use of a within subject design has many strengths, primarily a reduction of inter-individual differences, the current study is not without limitations. The duration of training in the current study (6 weeks) is relatively short, although we did observe increases in muscle size and strength, and so future studies investigating longer term adaptations are required. There is also the potential when using a within subjects design that there is cross-education between limbs which may mask any differences, due to training, between limbs (Carroll, Riek, & Carson, 2001). The cross education effect has been shown to result in an increase in strength of ~12% in the contralateral leg (Manca, Dragone, Dvir, & Deriu, 2017) although the magnitude of any effect is likely to be less in the current study where both legs were training, albeit at different intensities. There is also no evidence that the magnitude of the cross education effect is related to training load (Cirer-Sastre, Beltran-Garrido, & Corbi, 2017). Any cross education effect seen is in the current study is, therefore, likely to be small and similar between the different training loads. . The benefits and limitations of unilateral exercise studies has been discussed previously (MacInnis, McGlory, Gibala, & Phillips, 2017). On top of this we only considered a simple single joint exercise and whether similar findings are seen in women participating in resistance training involving more complex lifts remains to be investigated. We have also chosen to apply a single set of exercise to failure, as a simple and achievable intervention, at different loads. However, it is possible the gains in strength and muscle mass may be higher with a greater number of sets, frequency of sessions and, of course, duration of training but there is no evidence to suggest that this would result in differences between the high and low load groups. Further work is needed to investigate this

In conclusion the current study has shown that in women, when resistance exercise is performed in a single set to failure, the load at which exercise is performed, and indeed the training volume itself, do not determine the magnitude of the adaptive responses, in this case increases in muscle size and strength. Together with previous studies in men these data indicate that the current resistance exercise recommendations require to be updated to reflect these findings.

Declaration of interest statement

The authors have no conflicts of interest to declare.

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415 **Figures**

416 **Figure 1**

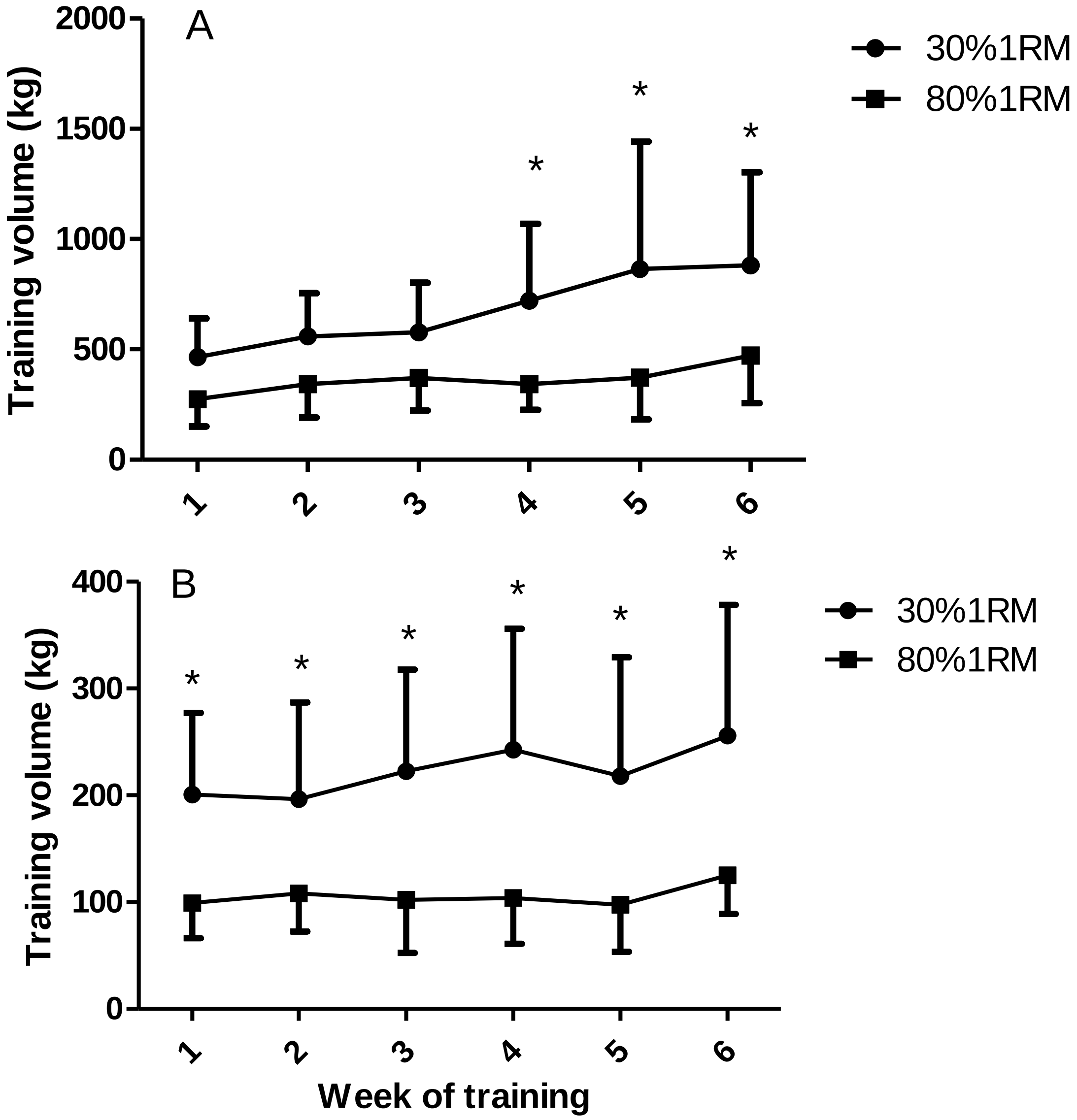

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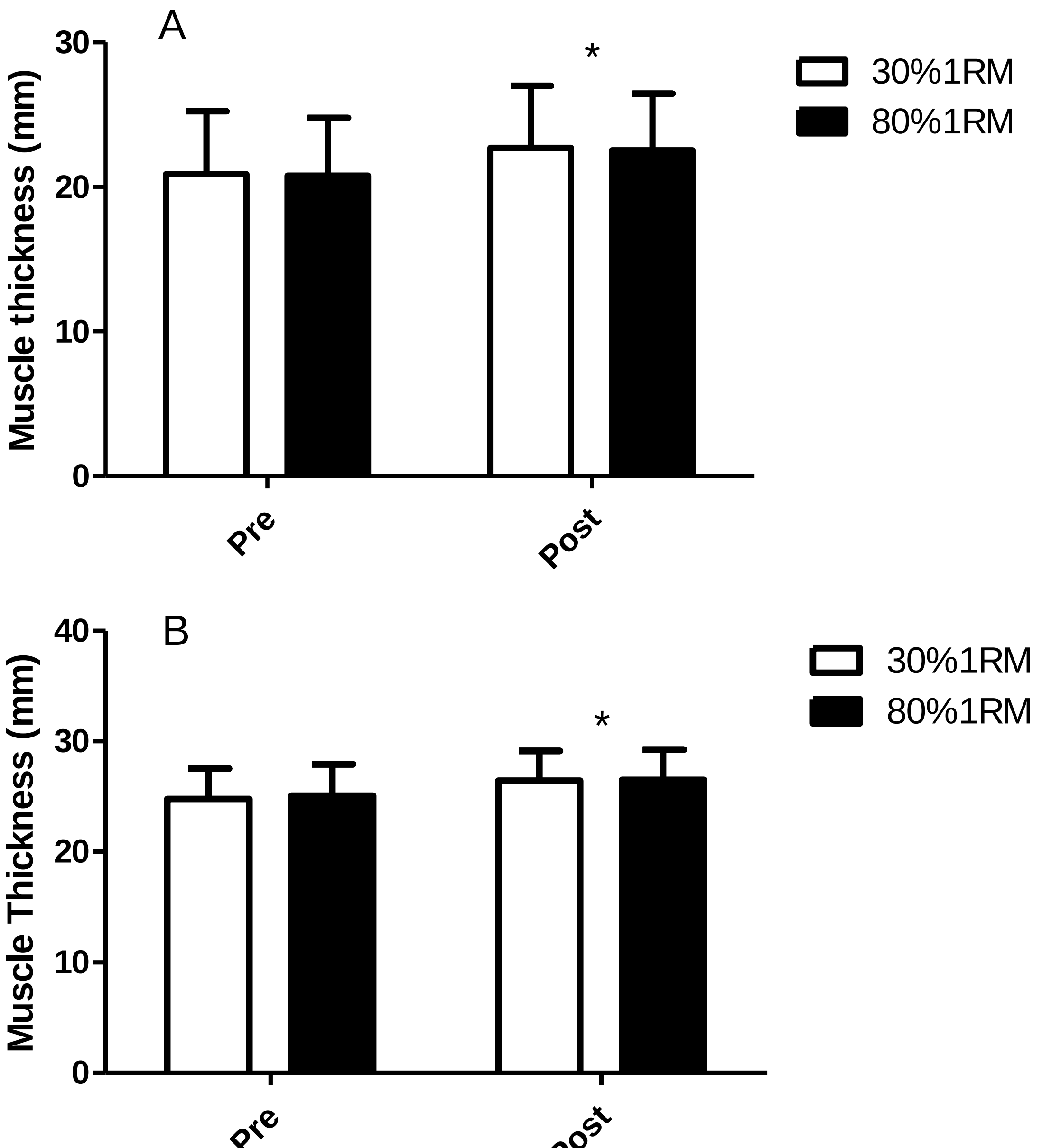
Figure 2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Muscle thickness (mm)
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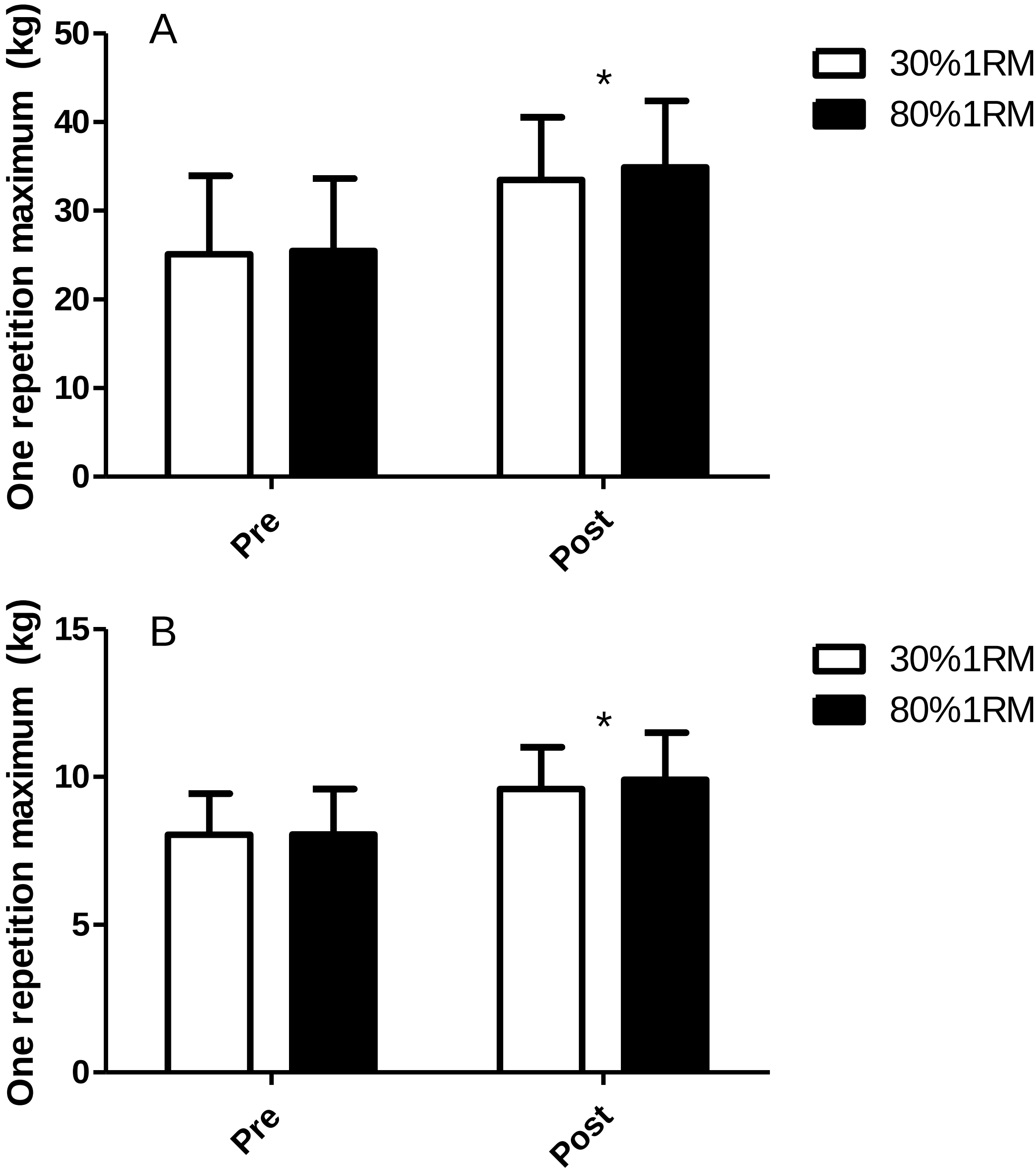
Post

Figure 3


A
One repetition maximum (kg)
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One repetition maximum (kg)
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Pre
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30%1RM
80%1RM

Figure captions

Figure 1. Training volume (number of repetitions * load) each week during the 6 week training period for the legs (A) and arms (B) at 30% and 80% of 1RM. * indicates a significant difference between groups.

Figure 2. Muscle thickness of vastus lateralis (A) and biceps brachii (B) before and after 6 weeks of resistance exercise training at 30% and 80% of 1RM. * indicates a significant increase with training.

Figure 3. Muscle strength of knee extensors (A) and elbox flexors (B) before and after 6 weeks of resistance exercise training at 30% and 80% of 1RM. * indicates a significant increase with training.