Title

Chain-loaded Variable Resistance Warm-Up Improves Free-Weight Maximal Back Squat Performance

Running head

Chain-loaded resistance squat warm-up

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Abstract

The acute influence of chain-loaded variable resistance exercise on subsequent free-weight one repetition maximum (1-RM) back squat performance was examined in 16 recreationally active men. The participants performed either a free-weight resistance (FWR) or chain-loaded resistance (CLR) back squat warm-up at 85% 1-RM on two separate occasions. After a 5 min rest, the participants attempted a free-weight 1-RM back squat; if successful, subsequent 5% load additions were made until participants failed to complete the lift. During the 1-RM trials, 3D knee joint kinematics and knee extensor and flexor electromyograms (EMG) were recorded simultaneously. Significantly greater 1-RM (6.2 ± 5.0%; $P < 0.01$) and mean eccentric knee extensor EMG (32.2 ± 6.7%; $P < 0.01$) was found after the CLR warm-up compared to the FWR condition. However, no difference ($P > 0.05$) was found in concentric EMG, eccentric or concentric knee angular velocity, or peak knee flexion angle. Performing a CLR warm-up enhanced subsequent free-weight 1-RM performance without changes in knee flexion angle or eccentric and concentric knee angular velocities; thus a real 1-RM increase was achieved as the mechanics of the lift were not altered. These results are indicative of a potentiating effect of CLR in a warm-up, which may benefit athletes in tasks where high-level strength is required.

Keywords: PAP, accommodating resistance, 1-RM, preconditioning, strength training

Introduction

Variable resistance training using bands or chains has been widely used in competitive powerlifting and in strength and conditioning programs for the development of strength and power capacity (Baker & Newton, 2009; Swinton, Lloyd, Agouris, & Stewart, 2009; Wallace, Winchester, & McGuigan, 2006). In successful free-weight one-repetition maximum (1-RM) back squat attempts, the barbell accelerates slowly in the early ascending phase of the lift (i.e. sticking point) as smaller internal and greater external moment arms are developed at the hip and knee joints (Elliott & Wilson, 1989; Newton, Murphy, Humphries, Wilson, Kraemer, & Hakkinen, 1997). Thus, reducing the external load in this phase (for example, by using variable resistance methods), while maintaining average loading throughout the lift may limit the impact of the sticking point allowing a large loading to be imposed. This enables the athlete to operate at near-maximal levels for a greater proportion of the movement, which likely provides a greater loading stimulus and thus may be a more effective training tool.

Imposing high-intensity activity on muscles during a warm-up can also acutely increase force production capacity and is often observed to improve lifting performances (Baker & Newton, 2009; Mina, Blazevich, Giakas, & Kay, 2014). This phenomenon is often referred to as post-activation potentiation (PAP) even when elicited using voluntary as opposed to electrically stimulated contraction conditions (Sale, 2002). The performance of maximal voluntary muscular contractions is thought to potentiate the neuromuscular system for several minutes via (1) improved phosphorylation of myosin regulatory light chains increasing Ca^{2+} sensitivity of the actomyosin complex (Sale, 2002), or (2) increasing the recruitment of higher order motor units through enhanced spinal excitability (Gullich & Schmidtbleicher, 1996) although increases in temperature, motivation and acute improvements in motor control strategies cannot be discounted. Regardless of the mechanism, maximal or near maximal contractions performed during a warm-up routine have commonly been reported to induce a potentiation response, enhancing mechanical power above previous capacity (Young, Jenner, & Griffiths, 1998; Gullich & Schmidtbleicher, 1996). The achievement of peak performance is dependent on the balance between fatigue and potentiation, i.e. high intensity (heavy load) exercise can potentiate the muscle groups involved but can also reduce maximum force generating capacity immediately after the contractions (Young et al., 1998), which may reduce the effect of mechanisms that elicit potentiation (Jo, Judelson, Brown, Coburn, & Dabbs, 2010). Performance enhancement is typically observed 4-12.5 min after the performance of maximal or near-maximal contractions (i.e. a conditioning stimulus) on subsequent explosive muscular activity to induce an increase in force production possibly when fatigue and potentiation processes predominate (Gullich and Schmidtbleicher., 1996; Jo et al., 2010; Kilduff, Owen, Bevan, Bennett, Kingsley, & Cunningham, 2008; Lowery, Duncan, Loenneke, Sikorski, Naimo, Brown, & Wilson, 2012; Young et al., 1998).

It has been suggested that the use of chains can alter the mechanics of traditional resistance exercises, allowing the lifter to move more explosively and maintain a high force production when elevating the barbell to its final position (Baker & Newton, 2009; Wallace et al., 2006). While improvements in peak force production (Wallace et al., 2006) and peak lifting velocities during the eccentric phase (Stevenson, Warpeha, Dietz, & Giveans, 2010) have been reported following the performance of contractions using elastic bands during a back squat exercise, only a limited number of studies have examined the use of chains to provide variable resistance, with equivocal findings reported. Ebben & Jensen (2002) found that the inclusion of chains set at 10% of the total load during a back squat exercise had no significant effect on force production or muscle electromyogram (EMG) activity when compared to a traditional free-weight resistance. Similarly, Coker, Berning, & Briggs (2006) found no significant difference in movement velocity or the rate and magnitude of ground reaction force application during the snatch or clean exercises (Berning, Coker, & Briggs, 2008) with only 5% resistance imposed via chains. In contrast, Baker & Newton (2009) reported significantly greater mean and peak lifting velocities during a bench press exercise with chain-loaded resistance set at 12-16% 1-RM compared to free-weight resistance alone. These disparate findings are likely due to different study methodologies and exercise tasks (e.g. bench press, clean, back squat), the selected magnitude of variable resistance, performance measures (1-RM, peak forces, EMG, joint angle/velocity), and participant characteristics (e.g. experienced/novice lifters).

The back squat exercise is commonly used as a fundamental training exercise across many sports for the development of lower limb strength and power (Stevenson et al., 2010; Young, 2006). However, to our knowledge only one study has examined the influence of variable loading (using elastic band resistance) on subsequent free-weight back squat maximal lifting performance (Mina et al., 2014). Therefore, the purpose of the present study was to examine the influence of another form of variable resistance (i.e. chain-loaded resistance) during a warm-up on subsequent free-weight 1-RM back squat performance compared to free-weight resistance alone. It was hypothesised that the variation in resistance elicited by chains during squatting in the warm-up would: (a) enhance subsequent free-weight squat lift performance (maximal load); and (b) alter lifting mechanics (i.e. knee angular velocities, peak knee flexion angle) and neuromuscular activity during the 1-RM test, when compared to the use of traditional free-weight squat warm-up.

Methods

Participants

Sixteen active men (age = 26 ± 7.8 y, height = 1.73 ± 0.2 m, mass = 82.6 ± 12.7 kg) experienced in weight training (>3 y) volunteered to participate in the study. The participants completed a written informed consent and pre-test medical questionnaire, had no recent illness or lower limb injury, and avoided strenuous exercise or stimulant use for 48 h prior to testing. Ethical approval was granted by the ethics committee at the University of Northampton in accordance with the Declaration of Helsinki.

Study design

A randomised, cross-over design was implemented to compare 1-RM free-weight back squat performance after two warm-up conditions; either using chain-loaded resistance (CLR; experimental) or free-weight resistance alone (FWR; control). Following a 5 min cycling warm-up, participants performed either a CLR or FWR task-specific warm-up and then attempted a free-weight back squat exercise at their previously determined 1-RM load. A 5% additional load was added for each successful lift, with a 5 min rest between attempts. The final successful attempt was considered their 1-RM. The study design timeline is presented in Figure 1.

(Insert Figure 1 about here)

Procedures

Participants visited the laboratory on three occasions each separated by at least 72 h under familiarisation, control and experimental conditions. In the first session, the participants were familiarised with all testing protocols, where their back squat 1-RM was determined. The participants initially performed a standardised warm-up procedure of 5 min cycling (Monark 874E, Varberg, Sweden) at 65 rpm with a 1 kg resistance load and 2 min later performed 2 sets of 10 back squat repetitions with an unloaded bar (i.e. 20 kg).

One-Repetition Maximum Assessment. Two minutes after the standardised warm-up during the first session the participants completed 8-10 repetitions at 50% of their estimated 1-RM with the load increased by 20% (3-5 repetitions) and by a further 20% (2-3 repetitions) with 2 min rest periods between sets. The load was then increased by 5% with 2-4 min rest between lifts until they failed to complete a lift; the load lifted in the previous successful attempt was recorded as their 1-RM (Baechle & Earle, 2000). To ensure that correct technique was utilised, participants were instructed to place the bar above the posterior deltoids at the base of the neck and position the feet shoulder width apart with the toes pointed slightly outward and attempt to squat to a position where the knee joint was flexed to ~90º before returning to a standing position; this was visually assessed by an experienced spotter throughout all testing procedures to ensure correct technique, safety during the lifts with subjects receiving strong verbal encouragement to promote maximal effort.

In the experimental trials, the standardised warm-up was replicated before the participants performed 2 preconditioning sets of 3 repetitions of back squat exercise in either the FWR or CLR condition (described below) at 85% of the previously determined 1-RM with 3 min rest between sets to prepare for the 1-RM trial. After 5 min rest, the participants attempted to lift their previously recorded 1-RM, and where successful, the participants increased the load by 5% until they failed to complete a lift with 5 min rest between each attempt. Any further successes resulted in an attempt with an additional 5% (i.e. 10% total) to the nearest 1kg. Similar to previous studies, the CLR was set at 35% of the total load (Mina et al., 2014; Wallace et al., 2006). To ensure a similar total load across conditions, half of the 35% load was removed from the bar during the preconditioning set. The mechanical properties of the chains (i.e. load-length relationship) were determined to allow 35% of the load to be generated from the chains. The participants stood on a force platform (FP4, HUR, Tampere, Finland) with 85% 1-RM load to determine the combined load of the chains and free-weights; data were then directed to a computer running Research Line software (v.2.4, HUR, Tampere, Finland). The Olympic bar was placed on the squat rack and then unloaded. The chains were then adjusted using modified collars and were attached equidistant to the sides of the bar with a portion of chains in contact with the floor to ensure stability. The bar was then lifted from the squat rack and the load from the chains was adjusted to increase the measured load by 35% of the 85% load when the participants were standing upright on the force platform. As an illustrative example, a 100 kg load in the FWR condition would require 35 kg (35%) to be generated from the chains in the CLR condition. Half of the 35 kg load (i.e. 17.5 kg) would be removed from the bar, leaving 82.5 kg combined with the 35 kg from the chains giving a total load of 117.5 kg in the standing position. Therefore, a range of 35 kg (35%) is achieved through CLR while maintaining an average loading of 100 kg throughout the lift, identical to the FWR condition.

Muscle activity

EMG data were collected during 1-RM attempts from vastus medialis (VM), vastus lateralis (VL), rectus femoris (RF) and semitendinosus (ST). The skin was shaved, abraded and cleansed with alcohol before placing skin-mounted bipolar double-differential active electrodes (model MP-2A, Linton, Norfolk, UK) over the muscle belly. EMG signals were amplified (gain = 300, input impedance = 10 GΩ, common mode rejection ratio ≥100 dB at 65 Hz) and directed to a high-level output transducer (model HLT100C, Biopac, Goleta, CA) before being converted from an analog to digital signal at a 2,000 Hz sampling rate (model MP150 Data Acquisition, Biopac). The signals were imported into AcqKnowledge software (version 4.1) and filtered using a second-order Butterworth filter (20-500 Hz band-pass) and converted to root-mean-squared (RMS) EMG with a 250-ms sampling window. The normalised EMG amplitudes (%MVC) were used as a measure of neuromuscular activity during the back squat exercises with peak and mean EMG activity recorded during the concentric and eccentric phases.

Motion analysis

A 3D motion capture system with four ProReflex cameras (Qualisys, Gothenburg, Sweden) operating Track Manager 3D (v.2.0) software was used by placing three spherical infrared reflective markers (20 mm) over the greater trochanter (hip), lateral femoral epicondyle (knee) and lateral malleolus (ankle) to determine knee flexion ROM and both mean and peak eccentric and concentric knee angular velocities during the 1-RM trials. Angular velocity (ω) was calculated as average and peak rates of change in angular position during concentric and eccentric phases, where $\Delta\theta$ is change in angular displacement and Δt is change in time, expressed as:

$$\omega = \Delta\theta / \Delta t$$

Raw coordinate data were sampled at 100 Hz and smoothed using a 100-ms moving average before joint angle and velocities were calculated using Track Manager 3D (v.2.0) software (Kay & Blazevich, 2009). Initial recordings were obtained with the participant in the anatomical position to enable knee angle data to be corrected (180° full extension) before knee flexion ROM and both peak and mean eccentric and concentric knee velocity data were calculated.

Statistical analyses

All data were analysed using SPSS statistical software (v.19.0); group data are presented as mean ± SE. Normal distribution was assessed using the Shapiro-Wilk test; no significant difference ($P > 0.05$) was detected in any variable indicating that all data sets were normally distributed. Separate repeated measures MANOVAs were used to determine the influence between conditions on peak and average eccentric and concentric velocities and EMG activity during initial 1-RM trials of the same load (136.1 ± 5.6 kg). Where MANOVAs revealed a significant difference, post-hoc analyses with Bonferroni correction were used to determine the location of the differences. A paired t-test was used to examine peak knee flexion angle between conditions. Further analyses were conducted on the greatest 1-RM performance between the conditions using the previously described analyses as above. A paired t-test was used to compare 1-RM load between conditions. Significance was accepted at $P < 0.05$ for all tests.

Reliability

Reliability measurement was established previously in our laboratory (Mina et al., 2014). No significant differences ($P > 0.05$) were detected in any measure and intraclass correlation coefficients (ICC) for EMG data ranged from 0.93 to 0.98, 0.91 to 0.95, 0.61 to 0.97, 0.97 to 0.99, and 0.94 to 0.96 for RF, VL, VM, ST and QF, respectively. ICCs for knee angular velocities ranged from 0.88 to 0.96 and the ICC for knee flexion angle was 0.97. Coefficients of variation (CoV) for EMG data (expressed as a percentage of the mean) were also calculated and ranged from 9.0 to 13.7%, 6.7 to 12.0%, 5.2 to 7.7%, 11.4 to 20.2%, and 5.4 to 10.0% for RF, VL, VM, ST and QF, respectively. CoV for knee angular velocities ranged from 6.1 to 8.2% and CoV for knee flexion angle was 1.8%.

Results

During the initial 1-RM attempt, all participants successfully lifted their previously determined (136.1 ± 5.6 kg) 1-RM after both conditions indicating that neither FWR nor CLR induced fatigue. No significant difference ($P > 0.05$) was found in peak or mean knee extensor EMG amplitudes during the eccentric (QF; peak = 17.3 ± 7.3%; mean = 29.2 ±

6.3%) (ST; peak = 5.8 ± 10.9%; mean = 2.8 ± 10.3%) or concentric (QF; peak = 15.9 ± 7.1%; mean = 9.7 ± 6.5%) (ST; peak = 16.3 ± 14.2%; mean = 14.0 ± 11.2%) phases of the lift. Similarly, no significant difference ($P > 0.05$) was found in peak or mean knee angular velocity during the eccentric (peak = 6.4 ± 4.4%; mean = 0.6 ± 6.8%) or concentric (peak = 16.7 ± 4.6%; mean = 11.2 ± 5.2%) phases of the lift. However, peak knee flexion angle was significantly greater (3.8 ± 1.8° more flexion; $P < 0.05$) following the CLR condition compared to the FWR condition (Figure 2).

(Insert Figure 2 about here)

Following the initial 1-RM attempt, the participants attempted a 5%, and if successful a further 5% (i.e. total 10%), increase of their initial 1-RM load. Whilst no participant successfully lifted a greater load following the FWR condition, 10 of the 16 participants (63%) were able to successfully increase their 1-RM (i.e. best) by up to 10% (mean 1-RM = 144.5 ± 6.0 kg) following the CLR condition (Figure 3), which resulted in a significantly greater 1-RM load in the CLR (6.2 ± 5.0%; $P < 0.01$) than the FWR condition.

(Insert Figure 3 about here)

During the final (i.e. best) 1-RM attempt, a significantly greater mean eccentric EMG was found in VL, VM, RF and QF (QF EMG increase, 32.2 ± 6.7%; $P < 0.01$) following the CLR condition compared to the FWR condition. However, no significant difference ($P > 0.05$) was detected in peak eccentric EMG (QF, 15.0 ± 5.6%) or concentric EMG (peak = 14.8 ± 7.5%; mean = 20.4 ± 12.1%) between conditions (Table I). In addition, no significant difference was found in peak or mean eccentric ST EMG (peak = 16.4 ± 8.9%; mean = 16.3 ±

11.6%) or concentric (peak = 10.6 ± 13.4%; mean = 9.3 ± 14.2%) phases of the lift. No significant difference (*P > 0.05)* was found in peak or mean knee angular velocity during the eccentric (peak = 11.3 ± 7.4%; mean = 9.5 ± 6.7%) or concentric (peak = 9.4 ± 7.4%; mean = 20.6 ± 6.9%) phases of the lift (see Table I). Despite a greater load being lifted, no difference in peak knee flexion angle (0.3 ± 1.8°*; P* > 0.05) was found (Figure 2), indicating that a similar back squat depth was achieved and that a full repetition was performed.

(Insert Table I about here)

Discussion

The present study compared the acute effects of CLR and FWR warm-up conditions on subsequent free-weight 1-RM back squat performance (i.e. maximal load) as well as the lifting mechanics and neuromuscular activity. All participants lifted their previously determined 1-RM following both warm-up conditions, indicating that neither condition induced fatigue. During the initial 1-RM attempt, the peak knee flexion angle was significantly greater in the CLR condition, which indicates that participants voluntarily squatted to a greater depth, while no difference was found in EMG or knee angular velocities during the eccentric phase. Despite the greater squat depth, concentric movement velocity was similar after both conditions. Importantly, the greater squat depth likely required more work to be performed and placed the participants at a position of poorer mechanical advantage due to the larger external moment arms developed and requirement for force at different (longer) muscle lengths at the hip and knee (Anderson, Sforzo & Sigg, 2008; Elliott & Wilson, 1989). These findings are consistent with a recent study where a greater squat depth was adopted despite moving at the same concentric knee angular velocity following the completion of a variable resistance warm-up using elastic bands (Mina et al., 2014). Thus, regardless of the method of variable resistance imposition (i.e. chains or elastic bands), subsequent attempts using the same load (during free-weight 1-RM back squat) appeared to be more easily tolerated without compromising lifting mechanics.

A principal aim of the study was to compare the acute effects of a CLR warm-up with traditional FWR warm-up on 1-RM maximal back squat performance. The main finding was that 1-RM load (i.e. best) was significantly greater (6.2%) following the CLR warm-up compared to the FWR warm-up, indicative of a potentiating effect and supportive of our hypothesis. Despite the increase in load lifted there was no difference in peak knee flexion angle (0.3°) or peak and mean knee angular velocities when compared to FWR alone, which provides strong evidence of a 'real increase' in 1-RM as the mechanics of the lift were not altered. Therefore, given that the squat depth and knee angular velocities were unchanged despite the greater load lifted we can partially accept the second hypothesis. The reduction in eccentric knee angular velocities in some participants in the present study might be associated with the need to reduce the momentum of the bar during the downward movement ensuring that sufficient impulse would be provided by the participants to decelerate and stop the bar. Equally, the additional load might have limited the concentric movement speed as predicted by the muscles' force-velocity relationships. The use of variable resistance during a 1-RM back squat exercise reduces the effective load near the sticking point in the early concentric phase of the lift whilst allowing greater loading later in the concentric phase where the joints are more extended, the internal moments arms are greater, external moment arms are smaller, and optimal muscle lengths are achieved (Anderson et al., 2008). The variable resistance counteracts the increasing mechanical disadvantage from moment arm changes and force-length characteristics of the lower-limb skeletal muscles at the hip and knee during the eccentric phase of the lift (Anderson et al., 2008; Elliott & Wilson, 1989), enabling the muscles to work closer to their maximum throughout the lift. This stimulus may have allowed for an enhanced potentiation effect and an increased 1-RM back squat performance.

The time period over which potentiation is induced is most notable within minutes of the conditioning activity (Lowery et al., 2012; Sale, 2002). In the present study, 1-RM load following the CLR condition was clearly increased 5 min after the preconditioning activity, which is consistent with previous studies that observed a maximal effect within 4-12 min (Lowery et al., 2012; Seitz, Trajano, Maso, Haff, & Blazevich, 2015). Despite significantly greater VL, VM and RF EMG activity being observed during the eccentric phase following CLR, no change occurred in the concentric propulsive phase, which may indicate that increased activity of the quadriceps was an unlikely mechanism underpinning the increased 1-RM. However, the increased eccentric EMG may be symptomatic of greater force enhancement (Edman, Elzinga, & Noble, 1978) or increased stretch shortening cycle activity (Doan, Newton, Marsit, Triplett-McBride, Koziris, Fry, & Kraemer, 2002). Thus additional contributions from the quadriceps cannot be excluded. Alternatively, the contribution of other muscles such as the hip extensors (e.g. gluteus maximus) may have underpinned the enhanced 1-RM back squat performance as a greater mechanical contribution from the hip extensors, rather than the knee extensors, has been reported when greater loads are lifted during squatting (Flanagan & Salem, 2008). One limitation of the present study is that hip extensor EMG activity and the impact of variable resistance on other joint complexes such as the hip flexion and torso angle were not measured as we were unable to place electrodes on gluteus in the present study. Also, whilst reflective marker was placed on the bar, no marker was placed on the hip joint because it was completely obscured at peak hip flexion angles in the squatting position in pilot testing therefore changes in torso angle associated with spinal or pelvic adjustments were not determined. Whilst the knee joint complex and quadriceps activity were a focus in the present study, future studies should examine specifically the changes at the joints and in other muscle groups.

In conclusion, the present data indicate that the incorporation of variable resistance into warm-up routines before training or competition may provide a greater potentiating stimulus to enhance 1-RM capacity in the back squat exercise than traditional non-variable exercise, which could be beneficial to strength-based athletes (i.e. powerlifters, Olympic weightlifters).

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Tables

Table I. Mean and peak EMG activity (%MVC) and knee angular velocity (rad·s^{-1}) during the eccentric and concentric phases of the final 1-RM free-weight back squat attempts.

Measure		Eccentric Phase		Concentric Phase	
		CLR	FWR	CLR	FWR
QF EMG	Mean	63.0 ± 3.9*	48.2 ± 2.7	78.6 ± 3.5	70.5 ± 6.3
	Peak	97.2 ± 6.3	85.8 ± 5.7	104.7 ± 6.2	93.9 ± 6.3
ST EMG	Mean	52.9 ± 6.4	54.0 ± 17.0	76.0 ± 11.2	75.7 ± 18.0
	Peak	85.9 ± 10.4	75.9 ± 18.9	125.7 ± 17.8	85.0 ± 12.8
Velocity	Mean	0.75 ± 0.08	0.85 ± 0.08	0.89 ± 0.09	1.16 ± 0.12
	Peak	1.67 ± 0.15	1.83 ± 0.19	3.14 ± 0.28	3.54 ± 0.31

Acronyms – EMG: electromyography, FWR: free-weight resistance, CLR: chain-loaded resistance, QF: quadriceps femoris, ST: semitendinosus, 1-RM: one repetition maximum. *Significantly ($P < 0.05$) different than FWR.

Figure captions

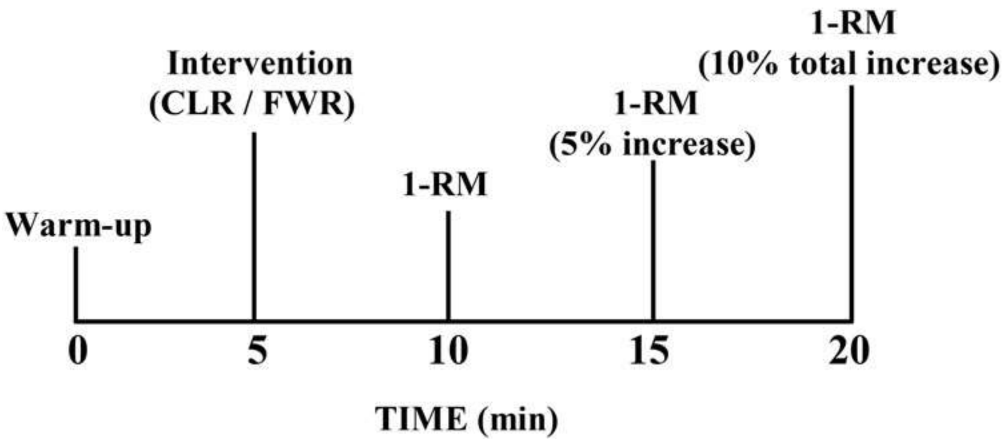

Figure 1. Study design timeline of the back squat warm-up and 1-RM protocol.

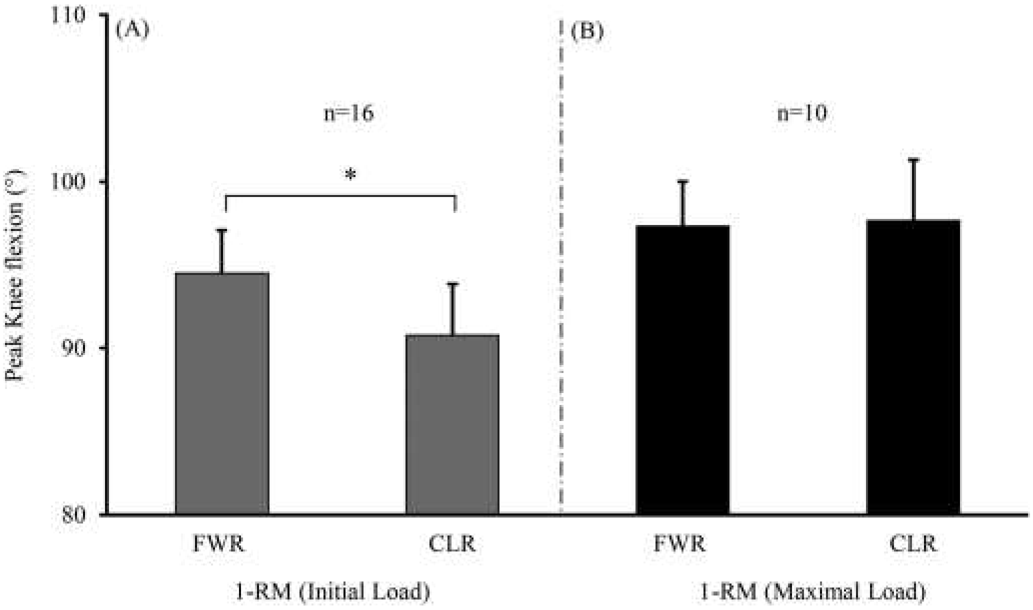

Figure 2. Peak knee flexion angle during the initial and maximal 1-RM back squat lifts. Significantly greater peak knee flexion (3.8 ± 1.8°) was observed following chain-loaded resistance (CLR) compared to free-weight resistance (FWR) warm-up under the same one repetition maximum (1-RM) load (Figure 2. A). No significant difference was found in knee flexion angle (0.3 ± 1.8°) during the final 1-RM attempts (Figure 2. B). *Significant to $P < 0.05$.

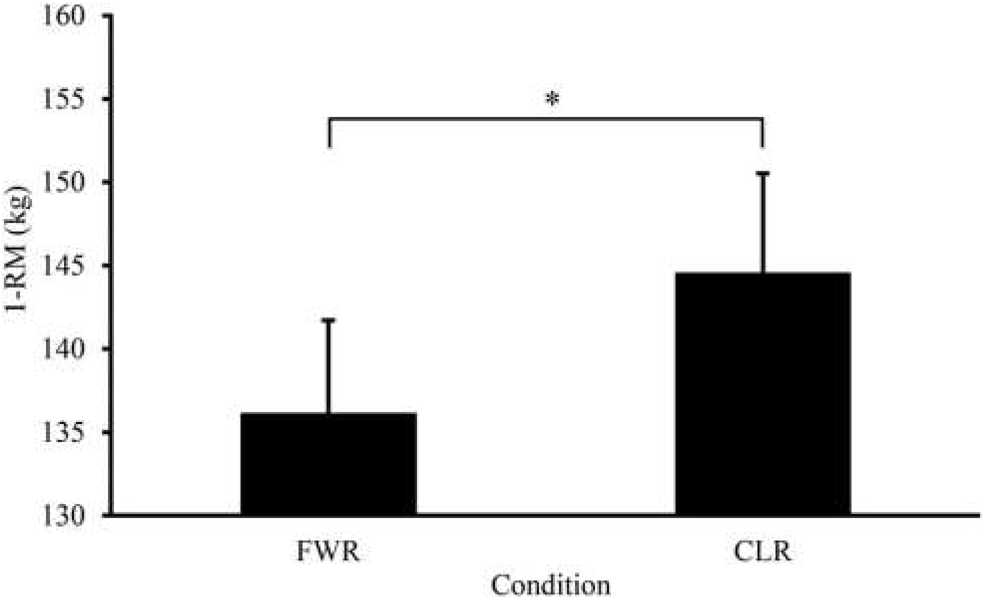

Figure 3. Final 1-RM load lifted following FWR and CLR warm-up conditions. A significantly greater (6.2 ± 5.0%) free-weight back squat one repetition maximum (1-RM) was achieved following the chain-loaded resistance (CLR) compared to the free-weight resistance (FWR) condition. *Significant to $P < 0.05$.