Neuromuscular response differences to power versus strength back squat exercise in elite athletes

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Running head: EMG, power, interpolated twitch force

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Abstract

The study's aim was to establish the neuromuscular responses in elite athletes during and following maximal 'explosive' regular back squat exercise at heavy, moderate and light loads. Ten elite track and field athletes completed 10 sets of 5 maximal squat repetitions on three separate days. Knee extension maximal voluntary isometric contraction (MVIC), rate of force development (RFD) and evoked peak twitch force (Pt) assessments were made pre- and post-session. Surface electromyography amplitude (RMS) and mechanical measurements were made continuously during all repetitions. The heavy session resulted in the greatest repetition impulse in comparison to moderate and light sessions ($p<0.001$), whilst the latter showed highest repetition power ($p<0.001$). MIVC, RFD and Pt force values were significantly reduced post-session ($p<0.01$), with greatest reduction observed after the heavy, followed by the moderate and light sessions accordingly. Repetition power significantly reduced during sets of the heavy session only ($p<0.001$), and greater increases in repetition RMS occurred during heavy session ($p<0.001$), followed by moderate, with no change during light session. In conclusion, this study has shown in elite athletes that the moderate load is optimal for providing a neuromuscular stimulus but with limited fatigue. This type of intervention could be potentially used in the development of both strength and power in elite athletic populations.

Keywords:

Neuromuscular, Resistance Exercise, Strength Training, Fatigue, Surface Electromyography

Introduction

Elite athletes perform different types of resistance exercises, to gain specific physical adaptations. For example, training for increasing muscle strength, involves lifting heavier loads i.e. 80 – 95% of 1 repetition maximum (RM) at a slower velocity (Aagaard et al. 2002; Campos et al. 2002). Conversely, to increase muscle power, the correct load selection is required to enable optimal velocity, according to the force-velocity-power relationship (Lynn and Noffal 2013). As such, the load is comparatively lighter (i.e. 50-60% of 1RM) than loads used for strength development training (Cronin et al. 2000, 2003).

When exploring some of the involved physiological mechanisms during and following differing types of resistance exercise; it is thought that neuromuscular fatigue related to central activation, or reduced neural drive, may be indicative of the necessary stimulus for enhanced muscle activation and ultimately maximum strength development (Häkkinen 1994). Furthermore, acute neuromuscular responses indicated by an increase in surface electromyographic (sEMG) signals during resistance exercise are purported to signify greater motor unit recruitment, and hence provide the neuromuscular stimulus required for adaptation (Pincivero et al. 2006; Ahtiainen and Häkkinen 2009; González-Izal et al. 2010).

The neuromuscular and fatigue responses to power and strength type sessions, have been studied in recreational athletes (Häkkinen 1994; Ahtiainen and Häkkinen 2009; Smilios et al. 2010) providing an indication of what might occur in elite populations; nevertheless, there is a paucity of information in elite populations. Importantly, these populations elicit relatively greater acute responses to resistance exercise (Ahtiainen and Häkkinen 2009), which maybe due to enhanced tolerance (Fry et al. 1994) provided by greater capacity to recruit additional motor units (Häkkinen et al. 1998; Aagaard et al. 2002; Aagaard 2003). Elite athletes commonly perform resistance exercise sessions using a variety of speeds and intensities (Schmidtbleicher 1992) to stimulate specific adaptations relevant to their event. Explosive lifting across a range of loads is also performed to optimise rate of force development (RFD) capabilities (Newton et al. 1997), which is important to improve athletic performance. Interestingly, literature relating to neuromuscular fatigue are based on indirect or limited evidence, as central fatigue cannot be assumed solely from changes in sEMG (Søgaard et al. 2006). However, specific measures such as central activation ratio (CAR) and evoked peak twitch force (Pt) can provide valuable information regarding central (e.g. motor neuron firing) and peripheral (e.g. excitation-contraction coupling) neuromuscular components of fatigue (Kent-Braun 1999).

To our knowledge, no studies have examined the within-session responses, or post-session neuromuscular fatigue in response to resistance exercise sets of explosive squat exercises performed with a range of loads. This is of particular interest to elite athletes that commonly perform explosive squat exercises, with a variety of loads to improve both power and maximum strength (Moss et al. 1997). It has also been proposed that the explosive effort required to move a load as fast as possible results in enhanced neuromuscular activation that is critical to develop both power and maximum strength (Behm and Sale 1993). Therefore, explosive lifting execution could influence the neuromuscular responses and hence further our understanding of the load that could optimise neuromuscular adaptation in this special population. As such, repetitive lifting of a heavier load will recruit more motor units at higher firing rates than a lighter load (De Luca 1997) and will result in earlier/greater fatigue due to less availability of non fatigued motor units to recruit (Dias da Silva and Gonçalves; Adam and De Luca 2005). Furthermore, the heavier load will take longer to lift than a lighter one (Perrine and Edgerton 1978; Gregor et al. 1979) resulting in greater time under tension which is likely to recruit a greater range of motor units (Burd et al. 2012) . In addition, possible greater alterations in ionic exchange and metabolite accumulation will result in reduced excitation-contraction (E-C) coupling to lower maximal force capacity (Allen et al. 2008), to contribute to premature fatigue. As such, it is likely that there is a central CNS strategy to alter neural recruitment, but it is also possible that, from the onset of fatigue, peripheral factors will contribute to any force decline. Therefore, there is limited evidence to be able to describe what the relative central peripheral contributions would be when comparing strength to power based training. Consequently, the aim of this study was to establish the neuromuscular responses during an explosive resistance exercise at 3 different loads designed to produce different power outputs in an elite athletic population. Specifically, we examine how RFD and maximal isometric voluntary contraction (MIVC) change, along with other neuromuscular measures to assess the nature and magnitude of fatigue. We hypothesised, that explosive, heavy load training will induce the greatest post-session central and relative peripheral fatigue and neuromuscular recruitment, during the exercise, when compared to the lighter loads.

Methods

Subjects

Ten male elite strength and power athletes were recruited (Table I); all were international standard competitors in sprint track and field events and had produced typical performances within 3 months of the study of 100 m sprint= ~10.25 s, javelin = ~78.33 m and triple jump = ~17.23 m. To put these performances into context, the International Association of Athletics Federation set qualification times and distances for London 2012 Olympics of 100m sprint 10.18 s(A) and 10.24 s(B); javelin 81.8 m(A) and 77.8 m(B) and; triple jump 17.20 m(A) and 16.85m(B). All of the athletes recruited for the study had a minimum of four years experience of regular squat exercise training. Each subject provided written informed consent following institutional research ethics committee approval.

Experimental Design

Familiarisation of all test procedures was performed, included 3-5 MIVCs to minimise the possibility of a learning affect on the subsequent test session days. On following days, comparisons of neuromuscular responses to moderate, heavy and then light loads were each performed as separate trials on 3 different days (but within a 2 weeks period) with at least one day of rest between sessions. This rest period ensured sufficient recovery to maintain the pre session MIVC on subsequent sessions. The trials were done in this order so the moderate session would act as a controlled dose to provide a protective effective for any damage occurring during the subsequent heavy session. The light session was used finally to minimise any fatigue effects that could influence athletic commitments following completion of all

3 trials. The protocol consisted of 10 sets of 5 repetitions “high intensity” (explosive concentric phase) barbell back squat exercise. Participants arrived at the testing centre at 08:00 hours following a 12 hour fast and consumed a standardised breakfast. As the study took place during the summer athletics competition season no resistance exercise took place between trials, only low intensity specific event training with a minimum period of complete rest 24 hours prior to arrival. The warm up consisted of 10 minutes (at 100 W) of cycling on an ergometer (Keiser M3, Keiser Corp, USA). Subjects then performed muscle function measures pre, mid (5 sets) and post exercise back squat session (Figure 1).

Muscle Function

Subjects were seated and secured in to an isokinetic dynamometer according to the manufacturers recommendations for the assessment of knee extension (Kin Com, Chattanooga, USA); briefly, the hip angle was 90° and the knee was secured at a 70°, where 0° was full extension. The exact position for each participant was recorded and replicated on subsequent testing sessions. Whilst in this set up the subjects performed evoked peak twitch force (Pt), MIVC (including RFD) and CAR.

Evoked peak twitch force (Pt)

Whilst positioned in the dynamometer subjects performed evoked peak twitch force (Pt), MVC (including RFD) and CAR. Two 4 x 8 cm electrical stimulation pads (Campbell Medical, UK) were attached to the proximal medial thigh aligned over the femoral nerve and over the greater trochanter (Nybo and Nielsen 2001; Lattier et al.

2004). The femoral nerve was located by identifying the femoral artery and placing the electrode approximately 2 cm laterally. Then the electrode was repositioned, until the optimal stimulation site was located by observing twitch response magnitude. Pt was assessed using a stimulator (StimISOC, Biopac Systems Inc, USA) to deliver sub-maximal single triangular pulses of 35 ms with a maximum constant of 200 V to the passive quadriceps as described previously (Markovic et al. 2004; Zory et al. 2010). Participants were instructed to relax the leg muscles and not anticipate the shock, so the full effect of the stimulation could be recorded. Pt values were taken as the peak change in force from pre-stimulated values recorded by the dynamometer.

Maximal Voluntary Isometric Contraction (MIVC) and Central Activation Ratio (CAR)

Subjects performed three warm up contractions, with increasing intensity followed by 3 X 7 s MIVCs with 60 s rest between efforts. The CAR assessment occurred during one of the MIVC trials, chosen at random and without warning. Subjects were percutaneously stimulated with a 250 ms 100 Hz tetanic pulse train (Nybo and Nielsen 2001), at the voltage pre-determined during the familiarisation session. The stimulation occurred six seconds into the MIVC test, with subjects instructed and coached to maintain consistent force levels during the stimulation (Kent-Braun and Le Blanc 1996). The trial resulting in the best peak force value was taken to represent MIVC force. Peak force was processed as the mean value from a 200 ms window centred on the peak force value. The same 200 ms interval was used to process pre trial MIVC RMS and also used as the reference sEMG value for normalisation.

The CAR value was obtained from the ratio of peak voluntary force (prior to the stimulation) to the peak stimulated force; where CAR = (MIVC force / superimposed stimulated force) x 100; (Kent-Braun and Le Blanc 1996; Nybo and Nielsen 2001). The RFD was calculated from the MIVC as the average slope of the force profile from 0-50, 0-100, 0-200 and 0-300ms (Aagaard et al. 2002). The onset of muscle contraction was defined as the point at which the force curve exceeded the baseline level by 5% of MIVC (Blackburn, et al 2009). Baseline resting torque was computed by taking the average reading over 0.5s, starting 1s before the onset of muscle contraction for MIVC.

Counter movement jump (CMJ)

Three maximal counter movement jumps (CMJ) were performed with a 30 s pause between each. Subjects held a wooden pole upon their shoulders during the jump to remove any extraneous movements from the arms (Markovic et al. 2004) and to attach a linear position transducer device (Celesco PT5A, USA) for measurement of jump height displacement.

Back Squat

The barbell load during the heavy session was determined during the familiarisation session. Full squats were defined by the hips descending below the level of the knee at the bottom of the movement (Newton 2006). Subjects performed a series of incrementally loaded sets of five repetitions and rated the intensity of the load against the active muscle RPE, with descriptive anchors provided at RPE = 11 and 20

(Gearhart et al. 2001). This scale has been shown to be a consistent method of assessing strength exercise intensity (Gearhart et al. 2001), giving exercise loads relative to maximum capabilities (Gearhart et al. 2002; Lagally and Amorose 2007). The exercise load used in the heavy intensity squat trials corresponded to an active muscle RPE = 16 or 17 (very hard). This method resulted in a mean ± SD barbell load of 129 ± 22 kg in the heavy session. Based upon the subjects' current repetition maximum squat load, this was equivalent to 6 ± 1 repetition maximum load, or ~85% of maximum (Shimano et al. 2006). During the moderate and light sessions, subjects lifted 75% and 50% of heavy session load, respectively, of the system mass terms. System mass was defined as the total barbell and 88% body mass which was assumed to be involved in the squat, as the remaining 12%, comprising the shank and foot segments, do not move vertically during this action (Zatsiorsky et al. 1990).

Using a standard squatting procedure (Brandon et al. 2011); during heavy and moderate sessions, subjects squatted down at a controlled speed in time to a metronome, emitting audio pulses at 1 Hz followed by an upward explosive maximal effort. During the light session, subjects performed the eccentric and concentric repetition cycle as fast as possible; however, subjects were instructed not to jump, so that repetition speed was optimised. This protocol is the type typically used for training of elite athletes whereupon to ensure maximum intensity of effort during the light load it is important to execute fast up and down phases of the squat. Whereas, to do the same during the heavier loads would be considered contraindicated due to the higher probability of incurring an injury during the eccentric phase, hence why it is important to control the eccentric phase. Blood lactate was assessed from earlobe capillary puncture using a portable device (LactatePro LT-1710, ArkRay Inc., Kyoto, Japan) at rest and after the 5th and 10th set. On completion of each training session, subjects provided an overall Rating of Perceived Exertion (RPE) (Borg 1973).

Squat Kinematics

Knee angle was captured during the squat using a flexible electrogoniometer (TDA-100, Biopac Systems Inc., USA) attached to the lateral aspect of leg. The knee angle measurements were used to determine the beginning and end of the concentric phase of the squat ensuring consistency of the period from which mean power and RMS values were processed between subjects and across sessions as described previously (Brandon et al. 2011). Barbell displacement data was also measured using the aforementioned linear position transducer and subsequently power was calculated using the system's software (AcqKnowledge ® 3.8.1, Biopac Systems Inc., USA): where, Force (load) = System mass x (Acceleration + 9.812), then, Power = Force (load) x Velocity. Power was processed as the mean power value from the time interval defined by maximum to minimum knee angle values as the barbell was being lifted upwards.

sEMG

sEMG was recorded during the MIVC and continuously throughout the back squat sessions. Following shaving, abrading and cleaning with alcohol swabs a pair 10 mm diameter electrodes (PNS Dual Element Electrode; Vermed, Vermont, USA), with 10 mm inter-electrode distance, was secured to the right vastus lateralis and biceps femoris (BF) muscle in accordance with the Surface ElectroMyoGraphy for the Non-Inva- sive Assessment of Muscles (SENIAM) guidelines (Hermens et al. 2000).

Raw sEMG was selected from the beginning to the end of the concentric phase of the squat as defined by maximum and minimum knee angles. From this sEMG amplitude was determined by transferring the raw signal to root mean square (RMS), which was obtained via bespoke sEMG amplifiers (Biopac Systems Inc., Santa Barbara, USA). The sEMG data was sampled at 2000 Hz and automatically anti-aliased and filtered using a 1 Hz - 500 Hz band pass filters. RMS was processed from the sEMG amplitude, using a 100 ms moving window and averaged at 10 Hz. RMS values during barbell squat repetitions and MVC and RFD were normalised to a reference RMS value captured during pre trial MVC; specifically from the average of the concentric phase of each movement (Brandon et al. 2011).

Within-set RMS was normalised to the first repetition of each set. To determine the influence of antagonistic activity under fatigue, RMS was also measured during the knee extension MIVC and squat exercise from the BF muscle (De Luca 1997; Weir et al. 1998; Hassani et al. 2006; Zory et al. 2010).

Statistical methods and analysis

Statistics were performed using Minitab 15 software (USA), which reports statistics to nearest three decimal places; all data were expressed as mean ± SD and statistical significance was accepted at $p<0.05$.. To compare differences between sessions and time a two factor repeated measures ANOVA test (session x time) was processed for MIVC, RFD, RFD: MIVC ratio, VL and BF RMS during MVC, VL RMS during RFD, CAR, Pt, CMJ height, and lactate. To compare session characteristics, a two factor ANOVA test (session x set) was processed for power, impulse, and repetition duration. To compare session differences in repetitions within sets and between exercises a three-factor ANOVA test (session x set x rep) was processed for RMS amplitude and power. For brevity these variables were used from sets 1, 5 and 10 only. Where necessary, effects were followed by *post-hoc* Tukey's tests. Due to methodological issues, not all measurements of evoked twitch and CAR assessments were recorded. Therefore, two factor ANOVA was performed with eight subjects for Pt and CAR.

Results

Power and work during back squats

As expected, repetition power (Table II) significantly ($F=1361.6$, $p<0.001$) increased across loads from heavy, to moderate and then light. Within each of the 3 sessions only the heavy load significantly ($F=8.9$, $p<0.001$) declined by sets 5 and 10 (Table II and Figure 2B). As such repetition duration ($F=1694.5$, $p<0.001$) and impulse ($F=2387.3$, $p<0.001$) were also significantly greater with increased session load (Table II).

sEMG during back squats

VL sEMG increased ($p<0.01$) within the sets as the repetitions progressed for all 3 loads. However, it was only during sets 5 and 10, significant increases were only shown with the heavy ($p<0.01$) and moderate ($p<0.05$) loads; the light load showed no significant increases (Figure 2A). No differences were shown for BF sEMG between loads and across reps and sets.

Muscle function tests

MIVC significantly (p<0.001) declined across pre, mid and post sessions for the heavy (13%) and moderate (9%) but not light loads (Table III and Figure 3B). However, RFD significantly, (p<0.001) declined across pre, mid and post sessions for all 3 loads with the heavy session declining by 28% in comparison to 13 and 15% for the respective moderate and light sessions (Figure 3A).

Pt significantly declined across pre- to post- heavy (p<0.01) and moderate (p<0.05) but not the light session (Table III). No significant differences were found for CAR and CMJ height within or between sessions. There was a significant reduction across all sessions combined for VL RMS during MIVC (F=7.9, p=0.001) and VL RMS during RFD (F=3.7, p=0.034) (Table III).

Lactate and RPE

Lactate was significantly greater (F=57.0, p<0.001) than the baseline (0.9 ± 0.3 $mmol.L^{-1}$) for post heavy and moderate (4.9 ± 2.5 and 2.6 ± 1.7 $mmol.L^{-1}$ respectively), but not for the light session (1.8 ± 0.9 $mmol.L^{-1}$). Post session RPE scores significantly (F=50.8, p<0.001) increased along with load showing 11.3 ± 2.4, 13.3 ± 1.8 and 16.5 ± 0.9, for light, moderate and heavy loads respectively.

Discussion

This study is the first to characterise the neuromuscular response during and following resistance exercise that elite athletic populations typically engaged in. This work provides novel information on resistance training prescription for elite, strength and power-trained populations. As hypothesised the heavy load produced the least power whereas the light load produced the most power during the back squat. Back squat repetition power, within the sets, declined for the heavy load but was maintained in the moderate and light loads. This caused a greater decline in MIVC post session when compared to the moderate and light loads.

sEMG during squats

VL sEMG recorded during the squats increased for the heavy and moderate loads across all 3 sets, whereas although the light load increased in the 1st set, it only showed negligible increases in the 5th and 10th sets. Therefore, it is possible that these increases observed during the heavy and moderate loads (sets 5 and 10) were caused from the recruitment of larger (type II) non-fatigued motor units to compensate for the smaller (type I) fatigued units (Dias da Silva and Gonçalves; Adam and De Luca 2005), which is indicative of submaximal fatigue (Moritani et al. 1986). In addition, the greater time under tension for the heavier loads (Table II) will result in recruitment of a greater range of available motor units (Burd et al. 2012), which will also contribute to the increased sEMG observed. However, it is evident that a possible neural compensation strategy was only effective in maintaining power in the moderate and not the heavy session. The residual impact of this fatigue was shown by a greater reduction in MVC and RFD following the heavy session. Also, the higher post-heavy session lactate suggests that metabolic factors, particularly the glycolytic pathway, could have contributed to the fatigue.

Muscle function tests

Firstly, there was evidence of peripheral fatigue following the heavy and moderate load sessions as Pt declined, whereas it was maintained following the light load. These reductions would likely have been derived from post-synaptic events such as an inhibition of the excitation-contraction coupling process (Hill et al. 2001). However, evoked twitch force values were small, relative to MVC, which limit conclusions based upon these findings but may be indicative of the highly trained status of the subjects (Garland et al. 2003). Secondly, no differences in CAR were shown across loads, therefore minimal central activation failure was responsible for the fatigue following the heavy load (Kent-Braun 1999). Thirdly, despite a greater reduction in MIVC following the heavy load, there was no difference for sEMG (recorded during MVC) across the loads. This is somewhat contradictory given the findings during the back squat, however MIVC is representative of a maximal force task as opposed to functional back squat, which is a submaximal position task. These differences are likely to produce very diverse excitatory and inhibitory input into the motor neurons of the spinal cord, which can result in altered neuromuscular recruitment strategies (Hunter et al 2004). Nevertheless, the increased decline in MIVC following the heavy load was caused by more peripheral post-synaptic factors, rather than reduced neural input. This might be an important consideration for “concurrent training” plans shortly after a heavy load strength session such as this. One other factor that could explain these observations is that this population was a highly trained, elite athletic population and conceivably the physiological responses and recovery could be faster than other populations described in the literature.

Summary

This study has shown that during the heavy back squat load the subjects' were unable to maintain the initial barbell velocity, as the repetitions and sets progressed. Whereas, during the light and moderate loads, the participants managed to successfully maintain velocity throughout all the sets. We therefore propose that during the moderate and light loads, the participants were able to employ a pacing strategy (Foster et al. 1994; St Clair Gibson and Noakes 2004), whereas during the heavy load they were not. Nevertheless, it has been well established that weight-training interventions are highly specific (Stone and Stone 2013), i.e. to achieve strength gains, to improve power, and so on. However, many elite athletic programmes require adaptations of both factors to achieve performance gains. Therefore, the medium load would be the optimal intervention as it produced increased neuromuscular recruitment, which is necessary for both strength and power adaptations (Takarada et al. 2000), but without the onset of appreciable fatigue.

Conclusions

This study has shown in a group of elite track and field athletes that heavy load explosive squat exercise increases neuromuscular recruitment, but fails to maintain power, thereby resulting in residual, peripheral fatigue. Conversely, the medium load also increased neuromuscular recruitment but was successful in maintaining power to produce less residual fatigue. The light load did not increase neuromuscular recruitment and maintained power, but completely avoided any residual fatigue. Therefore, athletes, coaches and practitioners seeking to bring about an adaptive response in both strength and power, the medium load (75% of heavy system mass load) is recommended to provide the necessary neuromuscular stimulus with less residual fatigue. Further investigations, that also measure contributions from hip muscles, are required to directly link the within-session neuromuscular responses to chronic strength or power adaptations.

Perspective

Back squat exercise is a routinely used resistance exercise to develop both strength and power in elite athletes, however there are no data that describe the physiological consequences of this activity. This is the first study in an elite group of athletes to characterise these acute neuromuscular responses of explosive back squat exercise performed with 3 different loads, to specifically produce 3 different power outputs. The range of measures, conducted in well controlled conditions substantially further our understanding of the physiological consequences for this exercise mode in this elite athletic population (Campos et al. 2002; Burd et al. 2012). The study provides critical information for athletes, coaches and practitioners seeking to use back squat interventions on elite athletes to obtain stimulation of the neuromuscular system; furthermore, it also provides critical information for exercise prescription and in particular consideration for implications of on concurrent training.

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Tables

Table I. Descriptive data of the subjects' physical characteristics.

Age (years)	Body mass (kg)	Vertical Jump Performance (cm)	Squat 1 Repetition Maximum Load (kg)	Isometric MVC knee extension force (N)
26 ± 3	86.0 ± 13	51 ± 5	152 ± 26	1175 ± 200

Values are given as mean ± SD, n = 10.

Table II. Power, impulse and repetition duration for set 1, 5 & 10 and total work for all sets during heavy, moderate and light sessions

		Heavy	Moderate	Light
Power (W)**	Set 1	1194 ± 203	1890 ± 344	2385 ± 299
	Set 5	1025 ± 215*	1964 ± 340	2509 ± 369
	Set 10	945 ± 218*	1932 ± 301	2475 ± 348
Impulse (N.s)**	Set 1	5349 ± 755	3327 ± 756	1064 ± 125
	Set 5	5601 ± 687	3194 ± 451	1107 ± 157
	Set 10	5723 ± 796	3277 ± 433	1102 ± 122
Repetition duration (s)**	Set 1	2.6 ± 0.2	2.1 ± 0.3	0.6 ± 0.1
	Set 5	2.8 ± 0.2	2.0 ± 0.1	0.7 ± 0.1
	Set 10	2.9 ± 0.2*	2.1 ± 0.2	0.7 ± 0.1

Values given as repetition mean ± SD, n = 10. * Significantly different Power and Repetition duration, $p<0.05$, compared to set 1 within Heavy session. ** Significant differences in Power, Impulse and Repetition duration between sessions, $p<0.001$.

Table III. Pre, mid and post session assessment values from heavy, moderate and light squat sessions.

		Heavy	Moderate	Light
MVC (N) $#	pre	1174 ± 200	1209 ± 234	1181 ± 182
	mid	1112 ± 163	1158 ± 233	1163 ± 173
	post	1030 ± 194**	1124 ± 251**	1155 ± 215
RMS during MVC (%) $	pre	100	100	100
	mid	96.9 ± 12.1	100.9 ± 11.0	98.9 ± 8.8
	post	92.3 ± 14.3	93.8 ± 11.0	90.8 ± 11.8
RFD ($N.s^{-1}$) $#	pre	6700 ± 912	6454 ± 822	6623 ± 1229
	mid	5162± 869**	5778 ± 807**	5840 ± 758**
	post	4872 ± 863**	5626 ± 1099**	5626± 1099**
RMS during RFD (%) $	pre	115.1 ± 18.1	123.4 ± 38.3	112.3 ± 29.3
	mid	90.9 ± 21.5	114.1 ± 37.9	107.9 ± 17.8
	post	100.6 ± 18.0	105.8 ± 26.6	97.4 ± 22.6
RFD: MVC (s^{-1}) $#	pre	5.78 ± 0.80	5.44 ± 0.83	5.63 ± 0.67
	mid	4.76 ± 1.19**	5.10 ± 0.88**	5.03 ± 0.51**
	post	4.85 ± 1.08**	5.08 ± 0.71**	5.08 ± 0.91**
Pt (N) $#	pre	33.5 ± 21.2	37.2 ± 12.9	36.0 ± 12.8
	mid	30.1 ± 16.6	29.2 ± 15.6	31.3 ± 12.5
	post	24.1 ± 13.8*	27.1 ± 14.8*	30.4 ± 12.8
CAR (%)	pre	94.8 ± 2.4	94.3 ± 3.1	95.6 ± 1.8
	mid	95.3 ± 2.3	94.5 ± 2.9	96.8 ± 1.6
	post	94.8 ± 4.2	95.4 ± 2.9	96.3 ± 1.7
CMJ Height (cm)	pre	51.2 ± 4.9	50.3 ± 5.3	51.4 ± 5.8
	mid	51.3 ± 5.3	51.1 ± 4.5	50.2 ± 5.8
	post	50.4 ± 4.5	50.4 ± 5.4	50.4 ± 6.5

Values given as mean ± SD pre, mid and post session, where n = 10 except for Pt and CAR where n = 8. Normalised RMS values are for the *vastus lateralis* relative to pre session RMS amplitude during MVC. $ Significant time effect from pre to post, $p<0.01$. # Significant interaction between load and pre to post session, $p<0.01$ Within session *post hoc* significant difference compared to pre-session values, * $p<0.01$ and ** $p<0.001$.

Figures

Figure 1 Timed summary of the Heavy, Moderate and Light High Intensity Squat Trials (T/C = testosterone and cortisol saliva samples, Lactate = blood lactate samples, Pt = evoked quadriceps twitch force, MVC = knee extension isometric maximal voluntary force, CAR = central activation ratio, CMJ = vertical jump height)

Figure 2 A) VL RMS amplitude and B) power, relative to repetition one (%) within sets 1, 5 and 10 of heavy, moderate and light sessions. Values given are the mean ± SD relative to repetition one of each set, n = 11. A) VL RMS amplitude * *post hoc* significant difference p<0.01 between repetitions 1 and 5 during heavy and moderate sessions. B) Repetition Power ** *post hoc* significant difference p<0.001 between repetitions 1 and 5 during set 5 and between repetitions 1 and 4 & 5 of set 10 of the heavy session

Figure 3 Relative change in A) RFD and B) MVC, expressed relative to pre-session values across heavy, moderate and light sessions, values given as mean ± SD, n = 10. * Significant difference between post-session values (p<0.01)

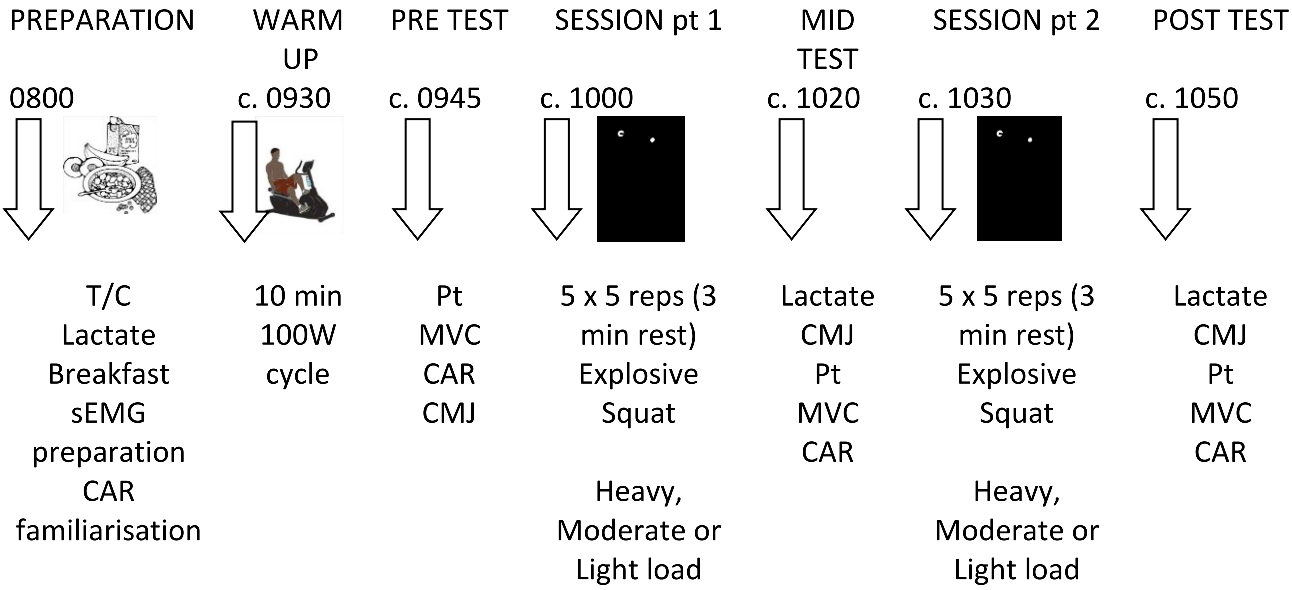
PREPARATION
0800
T/C
Lactate
Breakfast
sEMG
preparation
CAR
familiarisation
WARM UP
c. 0930
10 min
100W
cycle
PRE TEST
c. 0945
Pt
MVC
CAR
CMJ
SESSION pt 1
c. 1000
5 x 5 reps (3 min rest)
Explosive
Squat
Heavy,
Moderate or
Light load
MID TEST
c. 1020
Lactate
CMJ
Pt
MVC
CAR
SESSION pt 2
c. 1030
5 x 5 reps (3 min rest)
Explosive
Squat
Heavy,
Moderate or
Light load
POST TEST
c. 1050
Lactate
CMJ
Pt
MVC
CAR

Figure 1

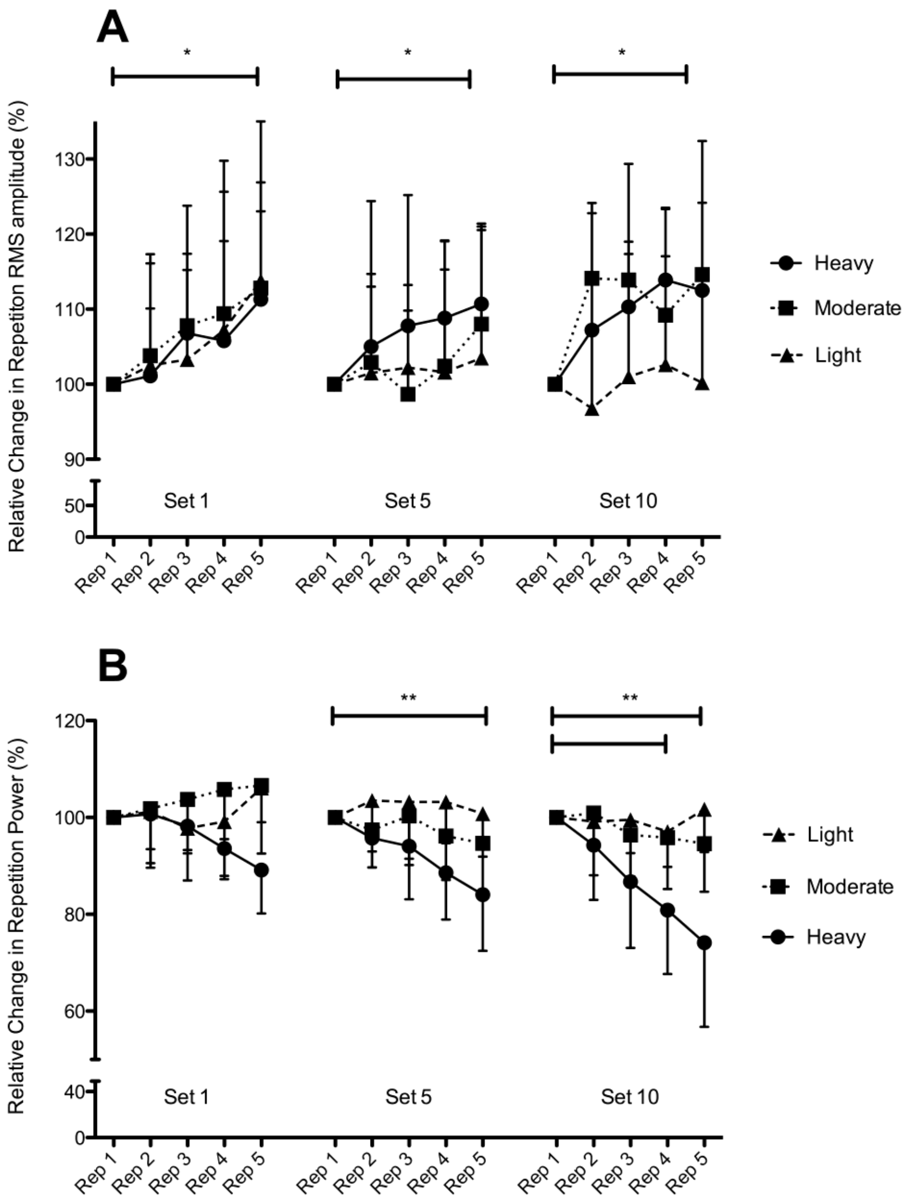
A
*
*
*
Relative Change in Repetition RMS amplitude (%)
130
120
110
100
90
50
0
Set 1
Set 5
Set 10
Rep 1
Rep 2
Rep 3
Rep 4
Rep 5
Heavy
Moderate
Light
B
**
**
Relative Change in Repetition Power (%)
120
100
80
60
40
0
Light
Moderate
Heavy

Figure 2

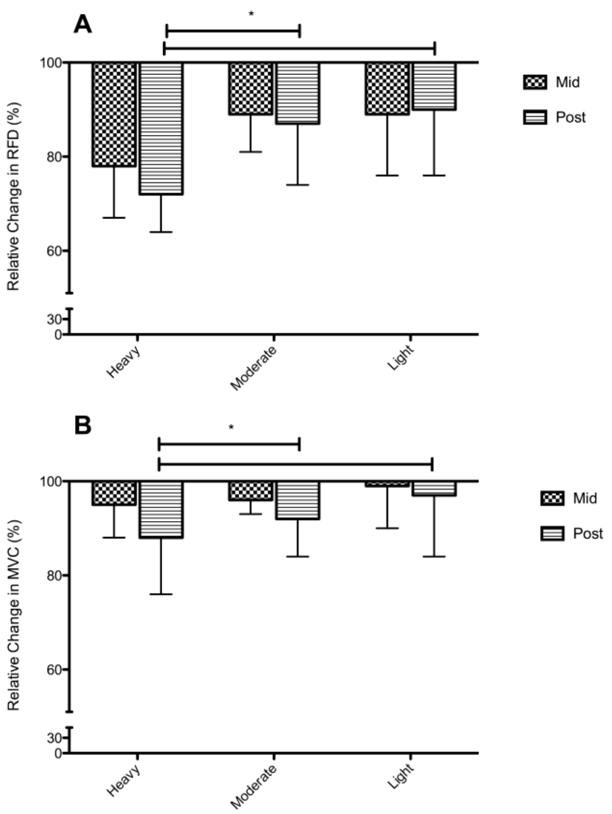
A
*
100
80
60
30
0
Relative Change in RFD (%)
Mid
Post
Heavy
Moderate
Light
B
*
100
80
60
30
0
Relative Change in MVC (%)
Mid
Post
Heavy
Moderate
Light

Figure 3