The response to, and recovery from maximum strength and power training in elite track and field athletes

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Abstract

There is a great deal of research on the responses to resistance training; however, information on the responses to strength and power training conducted by elite strength and power athletes is sparse. **Purpose:** To establish the acute and 24 hour neuromuscular and kinematic responses to Olympic-style barbell strength and power exercise in elite athletes. **Methods:** Ten elite track and field athletes completed a series of 3 back squat exercises each consisted of 4 x 5 repetitions. These were done as either strength or power sessions on separate days. Surface electromyography (sEMG), bar velocity and knee angle was monitored throughout these exercises and maximal voluntary contraction (MVC), jump height, central activation ratio (CAR) and lactate were measured pre, post and 24 hours thereafter. **Results:** Repetition duration, impulse and total work were greater ($p<0.01$) during strength sessions, with mean power being greater ($p<0.01$) following the power sessions. Lactate increased ($p<0.01$) following strength but not power sessions. sEMG increased ($p<0.01$) across sets for both sessions, with the strength session increasing at a faster rate ($p<0.01$) and with greater activation ($p<0.01$) by the end of the final set . MVC declined ($p<0.01$) following the strength and not the power session, which remained suppressed ($p<0.05$) 24 hours later; whereas CAR and jump height remained unchanged. **Conclusion:** A greater neuromuscular and metabolic demand following the strength and not power session is evident in elite athletes, which impaired maximal force production up to 24 hours. This is an important consideration for planning concurrent athletic training.

Introduction

Elite strength and power athletes use very specific resistance exercises to develop the physical attributes of maximum strength and maximum power. Sessions comprising high intensity (> 80% maximum load) and low repetitions (two to six) are often performed to develop maximum strength.[1] Adaptations to maximum strength training involve increased muscle fibre cross sectional area[2] and increased neural drive.[3] Conversely, lower load exercises performed at higher velocities are performed to develop power.[4] Power-type training also improves neural drive, particularly motor unit activation,[5] and increases the ability to generate force during higher velocity, dynamic movements.[6] Consequently, the adaptations following resistance exercise occur in both central and peripheral areas of the neuromuscular system and are largely specific to the training performed.

Fatigue can be globally defined as an exercise-induced decline in the ability to generate maximal voluntary muscle force[7] and is associated with reductions in central activation and neural drive, which are thought to provide (at least in part) the necessary stimulus for adaptations to strength training[8]. In addition, increased surface electromyographic (sEMG) amplitude during resistance exercise is indicative of greater motor unit recruitment and therefore provides the required stimulus for an adaptive response.[9,10] Interestingly, the neuromuscular responses to strength and power training have been examined in recreational athletes,[8,10] but very little information regarding elite athletes exist. Previous work has studied neuromuscular fatigue and recovery following very high intensity (20 x 1RM) and high volume (10 x 10RM) resistance exercise sessions[8,11] and found decreases in MVC for males and females immediately following the sessions, with incomplete recovery 24 h post-session.

A better understanding of the neuromuscular consequences following maximum strength and power resistance exercise might better inform the training plan in order to optimise adaptation, particularly in elite athletes. Additionally, the degree and nature of fatigue will likely determine the recovery time required, influencing the type of physical or technical training that is suitable following, or in conjunction with resistance exercise. For example, knowledge of neuromuscular function 24 h following maximum strength and power type resistance exercise will help coaches plan day-to-day sessions, given the multiple types of training that can occur across the cycle.

In the present study we had a rare opportunity to recruit elite athletes and expose them to the ‘typical’ training stimulus of Olympic-style barbell exercises that are regularly employed by elite track and field athletes (>10 sets)[12,13] when targeting the development of maximum strength and power. Therefore, the primary purpose of this study was to examine the acute neuromuscular and kinematic responses to maximum strength and power type resistance exercise and the subsequent 24 h recovery. The second aim was to examine male and female responses within this elite group, which might help inform whether the responses differ between sexes.

Methods

Subjects

Following institutional ethical approval, 10 performance programme athletes (Table 1) were recruited from UK Athletics Olympic Performance Centre, Lee Valley, London and health-screened before providing written informed consent. All volunteers were international standard sprinters or horizontal jumpers who regularly partook in barbell strength training.

A schematic of the experimental design is presented in Figure 1. The trials were completed following the competitive season when no sport-specific training was occurring. Following familiarisation athletes performed a maximum strength or power session in a randomised cross-over design within a seven day period. Each visit was preceded with at least one rest day. Females were assessed during the luteal phase of the menstrual cycle to limit hormonal variation on performance.

After arriving at the testing centre in a fasted state, blood lactate measures were taken (Lactate Pro, ARK Corp, Japan) and consumed a standardised breakfast. The training commenced with 10 minute warm up at 100 W on a cycle ergometer (Keiser M3, Keiser Corp, USA). Subjects performed the pre-session neuromuscular (NM) tests, comprising isometric knee extension force assessment (MVC), central activation ratio assessment (CAR) and a vertical jump test (CMJ). The maximum strength or power session was then performed; whole body barbell squat, split squat and press exercises. These exercises were selected as commonly used exercises employed by UK strength and conditioning coaches in delivering maximum strength and power programmes to elite athletes.

During each session, surface electromyography (EMG), barbell displacement and knee flexion (determined with electrogoniometry) were recorded. Based on a prior pilot investigation, blood lactate was collected 4 minutes following the completion of the final set to determine peak post-exercise lactate concentration. Ten minutes following the session, CMJ, MVC and CAR tests were repeated to assess the influence of the session on muscle function.[14] On completion of each session subjects provided a session RPE rating, using the Borg scale. To examine recovery following the maximum strength and power sessions, subjects returned to the testing centre the following day where MVC, CAR and CMJ assessments were performed following the aforementioned warm up procedure.

Subjects attended familiarisation not more than seven days before the initial trial. This included full instruction and practice of the MVC, CAR and CMJ assessments. In addition, barbell loads were determined for the maximum strength session of squat, split squat and push press. For each exercise, a series of incrementally loaded sets of five repetitions were performed, starting at a self-selected ‘moderate’ load, separated by three minutes rest between sets. At the end of each set, the intensity was rated (RPE), using the Borg scale (6 to 20). The load corresponding to an active muscle RPE = 16 or 17 (very hard) enabled the subjects’ exercise to be matched for relative intensity.[15] Whilst percentage of repetition maximum loads are often used, the use of RPE enables the determination of a load that is repeatable across all sets within the session and akin to training methods used by UK elite track and field athletes.[16]

Immediately prior to the warm up subjects were fitted with an electrogoniometer (TDA-100, Biopac Systems Inc., USA) attached to the lateral aspect of the left knee to determine the beginning and end of the concentric phase of the movement and synched with other instruments (such as EMG and the potentiometer) to determine the kinematics and the relevant epoch could be identified across sessions. Barbell displacement was measured using a potentiometer (Celesco PT5A, USA) attached to the barbell to estimate power during the lifting phase.[17] For the squat, speed squat, split squat and split squat jump repetition, the mean power was calculated from the whole concentric phase. For push and power press, the power calculation was limited to the period where the knee angle was decreasing and displacement was increasing. Power was calculated offline, where, force (load) = system mass × (acceleration +

9.812), then, power = force (load) × velocity. This was used to compare changes in power within sets during each session.

The duration of the combined lowering and lifting movement were used to define repetition duration of each exercise. From repetition duration and the derived force values, impulse was calculated as the integral of force over time. In addition, total work was obtained as the integral of power. Mean set values for concentric mean power, repetition duration, impulse and total work were determined from the average of the five repetitions. Total work performed during the entire maximum strength and power sessions were also compared; all calculations were computed off line (AcqKnowledge® 3.8.1, Biopac Systems Inc., USA).

Surface EMG (sEMG) was continually monitored throughout the strength and power sessions. The appropriate area was shaved, abraded and cleaned; 10-mm-diameter electrodes (PNS Dual Element Electrode; Vermed, Vermont, USA), with 10-mm inter-electrode distance were attached to the right *vastus lateralis* with the ground electrode attached to the patella.[18] The EMG data were sampled at 2000 Hz and filtered using 1 Hz - 500 Hz band pass filter. The root-mean-squared (RMS) amplitude was processed from the raw EMG amplitude using a 100 ms, overlapping window. RMS amplitude values were normalised to the value obtained from repetition one within each set.

The subjects performed the knee extension MVC force and CAR test as one combined assessment, using an isokinetic dynamometer (Kin Com, Chattanooga, USA). Subjects were positioned according to the manufacturer’s recommendations with 70° of knee flexion from full extension. Following three warm up contractions of increasing intensity, subjects were instructed to produce three, 7 s ‘ramp’ contractions (whereby maximum force was reached within 4 s) with 60 s rest between test contractions. Visual feedback, and strong verbal encouragement was provided throughout. The trial resulting in greatest voluntary force was used for data analysis and was processed as the mean value from a 200 ms window centred upon the peak force value.

During one randomly chosen MVC, and without warning, central activation ratio (CAR) was determined by percutaneous stimulation (StimISOC, Biopac Systems Inc, USA) of the femoral nerve with 250 ms, 100 Hz tetanic pulse train,[19] the intensity of which was determined during the familiarisation session; the optimum position was marked to ensure consistent placement on subsequent visits. The CAR was determined from the peak force prior to stimulation and the peak force during the stimulation;[20] from this, CAR = (MVC force / superimposed stimulated force) x 100.

Three maximal counter movement jumps (CMJ) were then performed with a 30 s pause between each. Subjects held a wooden stick across the shoulders during the jump to remove extraneous use of the arms. The stick also enabled the potentiometer (Celesco PT5A, USA) to directly measure jump height. The peak CMJ height from the three trials was used for data analysis.

Following the warm up and pre-session assessments, two sets of squat were performed at a self-determined ‘moderate’ intensity in order to provide an exercise-specific warm up prior to the sessions. A series of three exercises Using Olympic barbells, each exercise consisting of four sets of five repetitions, with three minutes rest between sets were completed, which accurately reflected elite training sessions for strength and power athletes on the Team GB Olympic track and field programme. Constant feedback was given to the athletes regarding range of movement, timing and speed during both sessions.

During the maximum strength session, the squat, split squat and push press were performed, in that order, using the pre-determined loads. The squat was performed with the bar resting across the shoulders, feet shoulder width apart and squatting down until the hips lowered to below knee and then standing back up during the concentric phase. The split squat also involved squatting and raising, with the barbell resting upon the shoulders; however, the right foot was forward with the left foot back. The movement involved squatting down, flexing at the hip and knee of the front leg and the knee of the back leg, whilst keeping the trunk upright. The push press was performed with feet shoulder width apart and holding the barbell in the hands across the front of the shoulders. The movement comprised a small squat down followed by synchronously pressing the bar over the head whilst standing back up. Subjects were instructed to perform the concentric phase of all movements over two seconds, which was controlled by a metronome.

During the power session the speed squat, split squat jump and power press were performed with 30% of the barbell load used in the maximum strength session.[5,21] During the speed squats, subjects were instructed to perform the eccentric and concentric repetition cycle as fast as possible, with a minimal jump in order to maximise repetition speed. Subjects performed the split squat jumps and power press with maximum acceleration in the concentric phase, following a controlled lowering phase.

All data are presented as mean ±SD. Differences between sessions for MVC, CAR, and CMJ were examined using a two factor (session, 2 × time, 3) repeated measures ANOVA, with one less level for lactate. Differences in sEMG between and within session a three factor (session, 2 × set, 4 × rep, 5) ANOVA was used. A further three factor ANOVA (session, 2 × exercise, 3 × set, 4) was used to determine differences in power, impulse, repetition duration and total work. Where necessary, effects were followed by Tukey's *post-hoc* tests. Given the gender differences, we explored post-session changes in MVC between male and female athletes using an independent samples t-test. In addition, regression analysis assessed the relationship between the post-session relative MVC and squat load, and also the relationship between the post-session relative MVC and the system mass (Barbell Load + (0.88 x body mass)) load used during the power sessions, expressed in relation to the maximum strength load. All data were performed on statistical software (Minitab v.15, USA); significance was accepted at $\alpha = 0.05$. Where appropriate, 95% lower and upper confidence intervals (CI) and Cohen's *d* effect sizes (ES) calculated by: Cohen's $d = Mean_1 - Mean_2 / SD_{pooled}$, where $SD_{pooled} = \sqrt{[(SD_1^2 + SD_2^2) / 2]}$. ES were then interpreted as ≤ 0.2 = trivial, 0.2-0.5 = small, 0.5-0.8 = moderate, ≥ 0.8 = large. Where significant and non significant main effects are described the mean ES and CI, between conditions, across all time points are presented.

Results

Significant interaction between the exercises and sessions were found for repetition duration (F = 18.13, $p<0.001$) impulse (F = 97.47, $p < 0.001$), total work (F = 8.38, $p = 0.004$) and mean power (F = 77.37, $p < 0.001$) – Table 2. *Post hoc* tests showed impulse and repetition duration were greater and power was less ($p < 0.01$; impulse speed squat ES: 3.6, CI: 2.06 to 4.82; split squat ES: 4.4, CI: 2.62 to 5.76; press push ES: 2.3, CI: 1.13 to 3.38) during all three exercises in the maximum strength session compared to the equivalent power session. *Post hoc* tests between equivalent exercises showed that only squat exercise had greater total work than the speed squat. However, the total work performed during the entire maximum strength session was significantly greater (F = 3.65, p = 0.008; ES: 1.34, CI: 0.32 to 2.29) than the power session.

Lactate (Figure 2.) showed a session and a session by time interaction effect (F = 57.56, $p<0.001$). Lactate values post- maximum strength session were higher than baseline (6.86 ± 2.2 versus 0.94 ± 0.2 $mmol.L^{-1}$; ES: 3.8, CI: 2.2 to 5.06), whilst post-power session lactate was relatively unchanged (0.89 ± 0.2 versus 1.2 ± 0.3 $mmol.L^{-1}$; ES: 1.2, CI: -2.11 to -0.22). Post-session RPE was higher (t = 11.92, p = 0.012; ES: 2.8, CI: 1.46 to 3.87) following the strength (16.5 ± 1.8) versus the power session (11.2 ± 2.0).

Repetition sEMG (Figure 3.) increased within sets for both sessions (F = 18.76, $p < 0.001$; ES: 0.28, CI: 0.035 to 0.36). For example, during set four of the maximum strength session, sEMG increased (relative to repetition one of each set) to 116.5 ± 14.3%, 125.8 ± 15.6% and 125.8 ± 15.6% for squat, split squat and push press, respectively. During set four of the power session RMS increased to 121.1 ± 18.5%, 102.0 ± 13.1%, and 112.7 ± 16.2% for speed squat, split squat jump and power press, respectively. There were session by set interaction effects (F = 4.78, p = 0.029); *post-hoc* tests revealed repetitions four and five were higher to repetition one ($p<0.01$; mean ES: 0.26, mean CI: 0.0255 to 0.3472) during all sets of maximum strength session, whereas repetitions four and five were only different during set one of the power session.

There were no differences in pre-session values between maximum strength and power session on any variable showing that athletes were in a similar physical condition between sessions (MVC- ES: 0.03, CI: -0.92 to 0.83; CAR-ES: 0.34, CI: -1.21 to 0.55; CMJ – ES: 0.19, CI: -0.69 to 1.07) (Table 3). There was a significant effect of the session on MVC (F = 9.37, p = 0.014) and across time (F = 7.83, p = 0.004). *Post-hoc* analysis revealed that following the strength session MVC was lower than pre strength MVC ($p < 0.01$; ES: 0.4, CI: -0.49 to 1.28) with no significant decline (ES: 0.17, CI: -0.71 to 1.04) demonstrated following the power session. Importantly, MVC was still depressed by a small amount 24 h following strength session ($p < 0.05$; ES: 0.23, CI: -0.66 to 1.10), whereas the restoration of MVC at 24 h post-power session was largely resolved. There were no main effects or interactions for CAR (ES: 0.24 CI: -1.11 to 0.65) or CMJ height (ES: 0.13 CI: -0.75 to 1.00).

The relative change in MVC for male (n = 6) and female (n = 4) subjects, expressed as a percentage of pre-session values, was 89.9 ± 9.3% versus 86.9 ± 5.8% post the maximum strength session and 98.6 ± 5.9% versus 86.4 ± 7.5% post the power session, respectively. T-test revealed the female subjects suffered significantly greater decrement, albeit by a trivial amount, in MVC post-power session compared to the males ($t = 2.88$, $p = 0.02$; ES: 1.8, CI: -0.23 to -0.00979).

There was a significant relationship ($r^2 = 0.705$, $p < 0.01$) between the athletes' strength during the squat exercise (determined as the system mass (bar mass + body mass) divided by body mass) and relative change in MVC (Figure 4A). In addition, there was a significant relationship ($r^2 = 0.744$, $p<0.001$) between the change in post-power session MVC (Figure 4B) and the relative load used during the power session in comparison to maximum strength session.

Discussion

This study investigated the consequences of strength and power sessions in elite track and field athletes. These data show increased neuromuscular activity throughout both training sessions, but there is an acute and prolonged (24 h post-session) reduction in function following the maximum strength training results, but not power.

The important findings were reduced MVC immediately following strength but not power sessions, whilst there were no changes in CAR or CMJ height. This is most readily explained by greater total work during strength vs. power session, accompanied by greater post-session lactate, suggesting greater metabolic challenge. This difference in decline following maximum strength and power concur with our previous results[16] and from those studies using machine-based exercise sessions with non-elite exercisers.[21] The reduction in MVC with no change in CAR suggests peripheral rather than central fatigue mechanisms were the dominant cause of MVC decline.[22] This observation disagrees with previous work,[8] based upon sEMG changes, that nervous system fatigue occurred.[21] However, other research using similar methods to the present study found no evidence of central fatigue following three sets of elbow flexion resistance exercise.[23] Consequently, comparing with these data on non-elite subjects might be somewhat futile given the obvious differences in training status; nonetheless it seems that structured resistance exercise, designed for maximum strength adaptation, result primarily in peripheral fatigue that is not evident following sessions designed to enhance maximum power.

Although previous findings are somewhat contradictory, the sport-specific training response in the current investigation has hitherto, not been reported for elite athletes. Muscle function assessments were conducted 10-minutes following completion of the final set, rather than immediately following the final repetition where ischemia or muscle pH changes could influence action potential propagation and contractile function, thus influencing outcome measures.[24] The choice of assessment timing could influence CAR measurement, as central fatigue recovers quickly post-exercise.[25] Therefore, it is conceivable that central fatigue was present immediately after training, but was resolved before the 10-minute post-exercise assessment.

Nonetheless, it was surprising that high intensity resistance exercise did not result in central fatigue given the neuromuscular system is heavily implicated in adaptation to maximum strength and power training.[3,26] It is also conceivable that central fatigue *per se* is not necessary to induce an adaptive response and we speculate that the ability to recruit the target areas of the neuromuscular system during the session is arguably the most important element of resistance exercise in elite athletes.

During both the maximum strength and power sessions, RMS increased within the sets, with no concomitant change in mean power. This indicates greater recruitment and/or firing rates, possibly of larger non-fatigued motor units. Somewhat intuitively, RMS increased more during strength than the power sessions, suggesting greater neuromuscular activation to maintain repetition performance, compared to lower load higher velocity repetitions.[25,27] The peripheral fatigue indicated by decreased MVC, could be attributed to localised muscle damage, although in trained athletes the repeated bout effect will limit the damage response.[28] Nonetheless, reporting of muscle soreness at 24 h might have provided indirect evidence of muscle damage. Alternatively, the accumulation of metabolites (evidenced by modest elevations in blood lactate) affected the release and re-uptake of Ca^{2+} in the sarcoplasmic reticulum and thereby impaired excitation-contraction coupling.[29] In either case, greater peripheral fatigue following maximum strength-type training provides a larger stimulus for muscle protein synthesis,[30] although both high and low load training has been shown to increases skeletal muscle hypertrophy in trained men.[31]

MVC was still depressed by ~6% below pre-session force following the maximum strength session which has important implications for subsequent exercise prescription and training programme design considerations for elite athletes. Previous research on non-elite populations[8,11,21] showed similar, but nonetheless larger effects;

however the load, used in these studies would not be used in optimal elite strength training programmes. In addition, muscle function changes in post-session relative MVC of male vs. female are somewhat limited by low numbers, but are still insightful given the elite nature of these athletes. Although, all of them showed reduced MVC post strength session (11-12%), only females reduced MVC post-power session by a similar amount, whereas the males maintained MVC. However, previous findings, using non-elite subjects showed similar reductions in MVC for both genders post power sessions[21] and that when females are matched for strength, there were no difference in fatigue to men.[32] Therefore, as we did not match strength it is possible that individual strength accounted for the difference in NM fatigue. Furthermore, we showed a strong relationship between strength and the relative change in MVC following the power ($r = 0.84$), but not strength session. This is likely to be from varied relative loading level used between subjects during the power session. Furthermore, the system mass load lifted during the power session (relative to the loaded lifted during the maximum strength session) was inversely related to the degree of change in MVC post power session (Figure 4B). Consequently, it is likely that MVC force reduction differences of male vs. female is weaker, lighter subjects were working ‘relatively’ harder during the power session than stronger, heavier athletes. Definitive gender differences are not possible to glean from these data in elite athletes, but it does highlight the importance of training intensities in a ‘system mass’ term because of the practical issues in exercise prescription. Setting load levels for power sessions as percentages of system mass loads might help ensure individuals train at a similar relative intensity.

Practical applications and Conclusion

In summary, these data provide new information of the fatigue and recovery following resistance exercise sessions designed to improve maximum strength and power in elite track and field athletes. The findings show that 12 sets of maximum strength resistance exercise results in reduced force generating capacity that take more than 24 h to be resolved, whereas force is largely unchanged following power sessions. This is likely from higher intensity and time under tension during the maximum strength session (impulse) and total work done. The study provides valuable information for athletes, coaches and practitioners when planning the training programme to understand the consequences of engaging elite athletes in strength and power resistance exercise. Specifically, in the day following maximum strength training there is likely to be an impairment of maximum strength; therefore practitioners should be mindful of appropriate programming particularly where subsequent maximal or perimaximal efforts might be required.

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Figure Legends:

Figure 1. Timed summary of the procedures assessing maximum strength and power sessions.

Figure 2. Pre- and post-session lactate during maximum strength and power sessions. Values given as mean ± SD, n = 10. ** Significant time difference for lactate, $p<0.01$ and $ significant interaction effect, $p<0.01$.

Figure 3. Normalised RMS amplitude within sets of maximum strength and power exercises. Mean values given relative to repetition one of each set, n = 10. * Significant difference between repetitions, $p<0.001$, $ significant interaction effect between set x repetition and exercise x repetition, $p<0.05$.

NB: Split squat set 1 and press set 1 were sets 5 & 9 of the sessions, respectively.

Figure 4. Relationships between relative change in MVC post power session and load level. A) Relative change in MVC versus relative squat load expressed as bodyweights (BW), where post MVC = 0.413 + 0.225 x SM load. ($r^2 = 0.705$, $p<0.01$). Jagged line shows 95% confidence intervals. B) Relative change in MVC versus load lifted during power session relative to maximum strength session (%), where post MVC = 1.88 - 1.58 x relative load ($r^2 = 0.744$, $p<0.001$). Jagged line shows 95% confidence intervals.

Table 1. Subjects’ physical characteristics; Values are given as mean ± SD.

	Age (years)	**Body mass (kg)**	**100m best time (s)**	**Squat 1RM (kg)**	**MVC force (N)**
Male, n = 6	28 ± 2	81.2 ± 12.2	10.44 ± 0.37	190.0 ± 38.0	1092.5 ± 245.1
Female, n = 4	26 ± 5	60.0 ± 3.7	11.73 ± 0.34	107.5 ± 12.0	821.0 ± 102.8

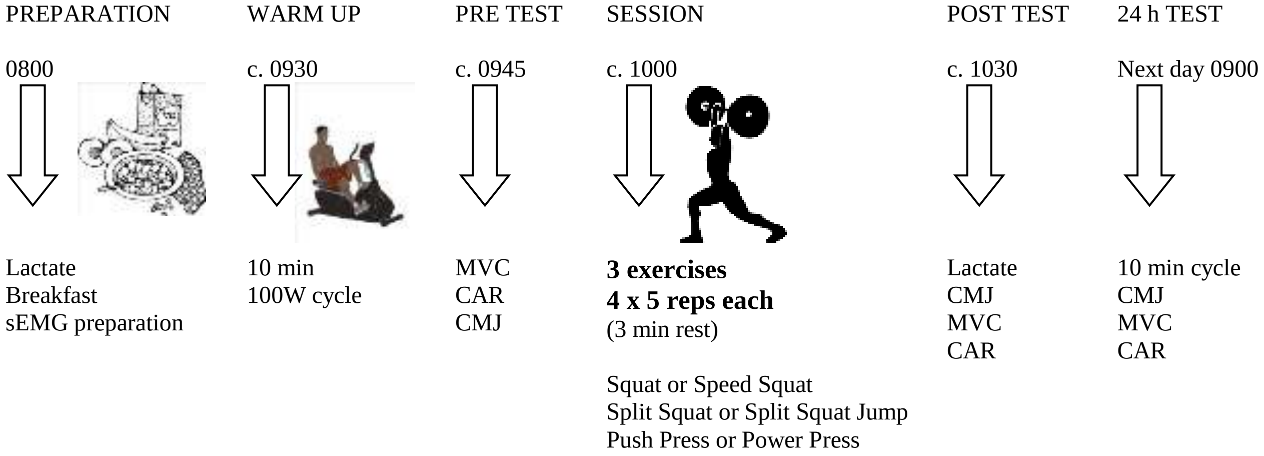
Table 2. Repetition duration, impulse, mean power and total work data during squat, split squat and press during maximum strength and power sessions. Values are given as mean ± SD. Significant session x exercise interaction effects p<0.01 were found for all variables with * significant difference between exercises within the sessions shown, p<0.01. ** Significantly different between strength and power session, p<0.001.

	Repetition Duration (s) **	**Impulse (N.s) ****	**Mean Power (W)****	**Total work (J)**
Maximum Strength (n=10)				
Squat (S)	3.4 ± 0.28	5676 ± 1854	528 ± 245	1791 ± 756*
Split Squat (SS)	3.3 ± 0.3	4578 ± 1175	340 ± 130	1089 ± 370
Press (Pr)	1.9 ± 0.7*	2072 ± 806*	988 ± 389*	1074 ± 334
Maximum Power (n=10)				
Squat (S)	0.8 ± 0.2	934 ± 228	1234 ± 385*	1004 ± 344
Split Squat (SS)	0.8 ± 0.2	887 ± 206	1760 ± 582*	1119 ± 422
Press (Pr)	0.6 ± 0.2	692 ± 194	3297 ± 1298*	1049 ± 368

Table 3. Maximum voluntary contraction (MVC), central activation ratio (CAR), and counter movement jump (CMJ) height at pre, post and 24 h post strength and power sessions. Values are given as mean ± SD, n = 10. **Significant difference ($p < 0.01$) to pre strength session MVC and post power session MVC; * Significant different to pre-strength MVC ($p < 0.05$).

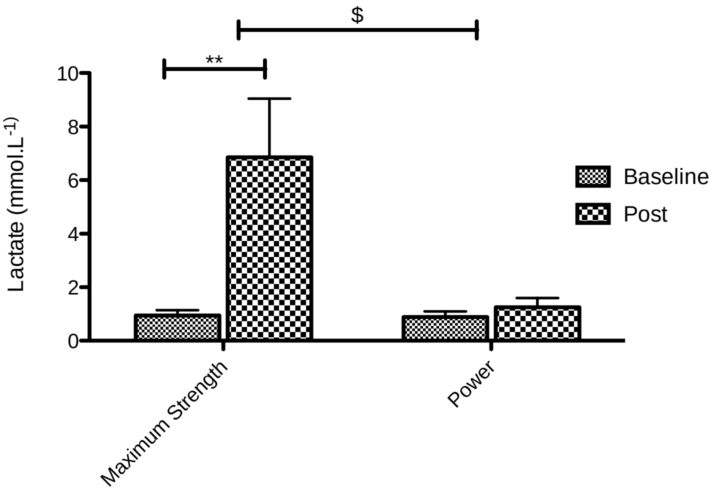
		Strength	**Power**
MVC (N)	**pre**	975.5 ± 246.7	983.9 ± 237.8
	post	871.9 ± 255.2**	937.6 ± 298.7
	24 h	920.5 ± 226.2*	953.3 ± 233.8
CAR (%)	**pre**	92.6 ± 4.4	94.2 ± 4.9
	post	93.5 ± 3.0	95.4 ± 3.9
	24 h	92.7 ± 4.7	93.2 ± 4.2
CMJ Height (cm)	**pre**	49.1 ± 9.8	47.1 ± 10.5
	post	47.8 ± 10.4	47.4 ± 11.1
	24 h	48.6 ± 8.9	48.7 ± 8.8

Figure 1.


PREPARATION
0800
Lactate
Breakfast
sEMG preparation
WARM UP
c. 0930
10 min
100W cycle
PRE TEST
c. 0945
MVC
CAR
CMJ
SESSION
c. 1000
3 exercises
4 x 5 reps each
(3 min rest)
Squat or Speed Squat
Split Squat or Split Squat Jump
Push Press or Power Press
POST TEST
c. 1030
Lactate
CMJ
MVC
CAR
24 h TEST
Next day 0900
10 min cycle
CMJ
MVC
CAR

521 **Figure 2.**

522



523

524 **Figure 3.**

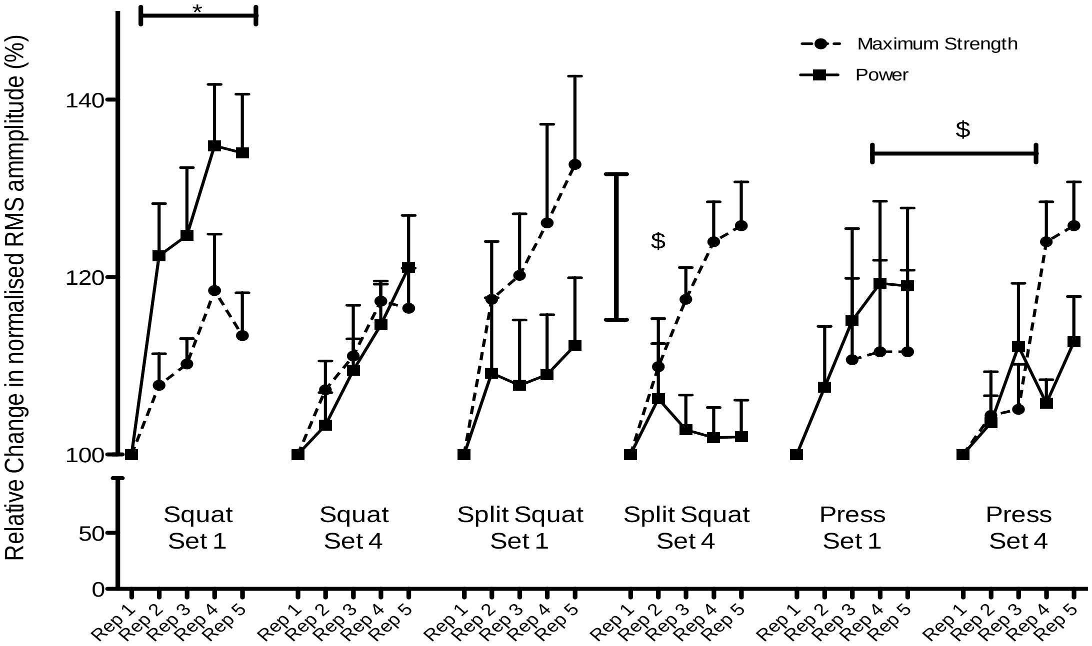


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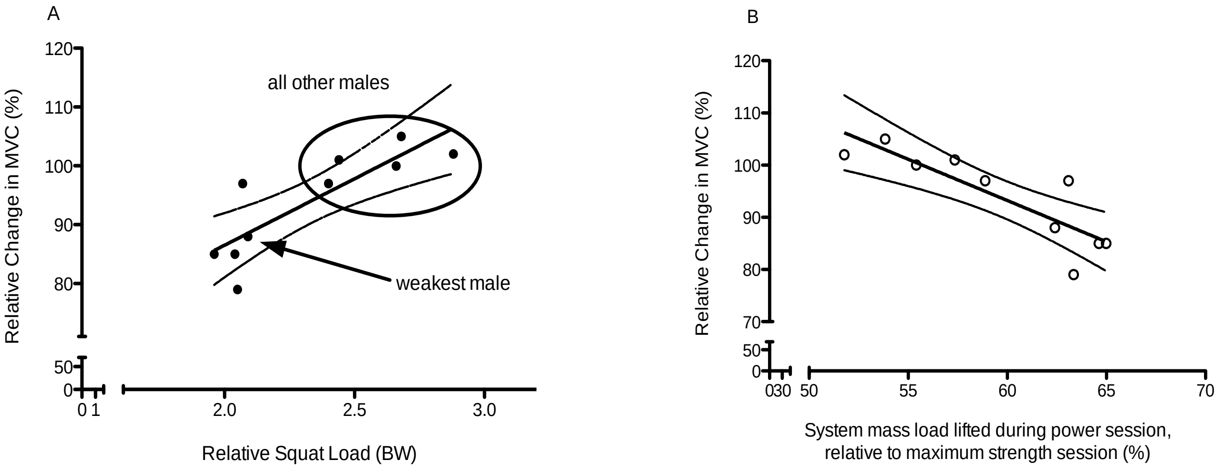
Figure 4.


A
Relative Change in MVC (%)
120
110
100
90
80
50
0
0 1
2.0
2.5
3.0
Relative Squat Load (BW)
all other males
weakest male
B
Relative Change in MVC (%)
120
110
100
90
80
70
50
0
0 30
50
55
60
65
70
System mass load lifted during power session, relative to maximum strength session (%)