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Acute neuromuscular and endocrine responses to two different compound exercises: squat versus deadlift

***Running head**: Squat vs. deadlift: which is more fatiguing?*

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ABSTRACT

Anecdotally, it is believed that the deadlift exercise brings about greater levels of central fatigue than other exercises; however no empirical evidence exists to support this view. Additionally, little is known about the acute endocrine response to heavy deadlift exercise and how this may differ to other similar compound exercises. Therefore, the aim of this study was to identify and compare the acute, neuromuscular and endocrine responses to squat and deadlift exercise. Ten resistance trained males completed 8 sets of 2 repetitions at 95 % of one repetition maximum. Maximum voluntary isometric knee extensor force (MVIC), along with measures of central (voluntary activation (VA) and surface electromyography (EMG)) and peripheral (electrically evoked control stimulus) fatigue were made prior to and 5 and 30 min post-exercise. Additionally, salivary testosterone and cortisol were measured at these same time points. MVIC was reduced after the completion of both exercises ($p = 0.007$) however no difference between exercises was evident. Similarly, although VA changed over time ($p = 0.0001$) no difference was observed between exercises. As a measure of peripheral fatigue, force from the control stimulus changed over time ($p = 0.003$) with a greater decrease evident after the squat ($p = 0.034$). EMG was reduced over time ($p = 0.048$) but no difference was seen between exercises. No change was seen in testosterone and cortisol. Even though a greater absolute load and larger volume-load was completed for the deadlift, no difference in central fatigue was evident between the two compound exercises. The greater peripheral fatigue observed after squat exercise may be due to the greater work completed by the quadriceps with this exercise. These results suggest that separate periodization, tapering and programming considerations may be unnecessary when using the squat and deadlift to develop muscular strength.

Keywords: voluntary activation, electromyography, resistance exercise, central fatigue

INTRODUCTION

When performed with appropriate loads and volumes, resistance exercise provides a potent stimulus for the development of muscular strength (31). However, while chronic adaptation may occur over time (1, 14), acute fatigue has the potential to disrupt homeostasis (33) and impair subsequent performance in the hours and days after the exercise bout. While contributing to post-exercise fatigue, acute changes in processes distal (peripheral fatigue) and proximal (central fatigue) to the neuromuscular junction (29) may provide stimulus for chronic adaptation to resistance exercise (1, 14, 40). In an attempt to better understand the neuromuscular response to resistance exercise, comparisons have been made between: loads used to develop strength, power (8, 36, 37), hypertrophy (38, 45) and the effects of various contraction types (4). The type of resistance exercise used in these previous studies varies from the use of single joint movements (6) to the use of exercises that utilize multiple joints, and therefore a large amount of muscle mass, for example compound exercises such as the leg press (37, 45) and squat (8, 17, 38). This previous research suggests that neuromuscular fatigue, typically measured as change in isometric force development and altered surface electromyography (EMG) signal (29, 35, 44), is most prevalent when a high volume of compound exercise is completed using a heavy load (> 80% of one repetition maximum (RM)). However, it is not clear whether different exercises bring about different levels of fatigue and whether this fatigue is predominantly peripheral or central in origin.

Anecdotally, there is a popular belief amongst athletes, coaches and practitioners that the deadlift exercise brings about a greater central fatigue than other exercises, including the squat. This perception was recently highlighted in a questionnaire of elite New Zealand powerlifters who stated that, in comparison to other exercises, they periodize and taper the deadlift differently, as it takes longer to recover from this exercise (39). Without evidence of this greater fatiguing effect, the authors of that study speculated that the higher absolute load and larger amount of muscle mass used when performing the deadlift may be responsible for the perceived differences between exercises.

In addition to the neural stimulus provided by resistance exercise, acute alterations in hormone secretion are likely to contribute to the chronic neuromuscular adaptations observed after a prolonged period of training (9). Elevations in testosterone and cortisol, for example, are thought to play important roles in post-exercise muscle recovery, remodelling and adaptation (32, 33) and therefore there is significant interest in how these hormones respond to various exercise parameters. As with the fatigue response to resistance exercise, the endocrine response to various loads (20, 37), volumes, rest periods (30) and exercise types (2, 42) have been explored. While a comparison between free weight and machine weight exercises has been made (28, 42), the endocrine response to two similar, lower body free weight compound exercises has not yet been investigated. Additionally, while the squat has been used in several studies (20, 41, 42) little is known about the endocrine response to the deadlift. Fahey et al. (10) used the deadlift to investigate testosterone responses in college athletes, however this appears to be the only study to use this exercise and, as such, a better understanding of the acute endocrine responses to the deadlift is warranted.

The aim of this study was to compare the acute effects of the squat and deadlift on 1) measures of neuromuscular fatigue and 2) testosterone and cortisol **concentration**. Given the popular belief that the deadlift has a greater effect on the central nervous system (CNS), i.e more fatiguing, than other exercises, we hypothesised that both exercises would bring about significant, acute neuromuscular fatigue and that this would be of a greater magnitude after completion of the deadlift. Similarly, as the endocrine response to resistance exercise is dependent, in part, on the quantity of muscle mass used (30), we further hypothesised that a greater endocrine response would occur after the deadlift.

METHODS

Experimental approach to the problem

Subjects completed a familiarization, two 1RM testing sessions and two experimental trials. The 1RM testing sessions were separated by 2.7 ± 0.68 (mean ± SD) days and 1.1 ± 0.32 weeks separated each experimental trial; testing was carried out between 2 pm and 6 pm and subjects completed each of their trials at the same time of day. During experimental trials, subjects completed 8 sets of 2 repetitions at 95 % 1RM of either the squat or deadlift exercise, the other exercise was completed for the second trial. Using a cross-over design, exercise order was allocated randomly, in a balanced fashion. **Neuromuscular function (EMG and transcutaneous electrical stimulation (TES)) and endocrine responses (salivary free testosterone and cortisol) were measured immediately prior to the warm-up and 5 min and 30 min post-exercise.**

Subjects

Ten resistance trained males (age = 24.0 ± 3.6 years, mass = 96.5 ± 22.2 kg, squat 1RM = 158.2 ± 23.4kg, deadlift 1RM = 191.5 ± 31.4 kg) volunteered to participate in this study. All subjects had at least 2 years of recreational resistance training experience, were familiar with the exercises used, including squatting to parallel depth, and were training at least 3 times per week leading into the study. This study was approved by the University Human Ethics Committee and all subjects provided written, informed consent.

Subjects were asked to abstain from any exercise in the 48 hours prior to each experimental trial and to maintain their normal dietary habits on the day of testing. Additionally, on the day of each trial, they were instructed to abstain from food 2 h before each trial and avoid supplements or foods that may have a stimulatory/ergogenic effect.

Familiarization and 1RM testing

During familiarization, subjects completed at least 5 maximal voluntary isometric contractions (MVICs) to ensure that they were able to maintain a consistent, maximal force output for 5 s (43). Subjects were then familiarized with TES (see Neuromuscular function section for procedures) and the maximal output current (346.6 ± 64.1 mA) was established via stimuli of increasing amplitude, applied to the resting muscle. Maximal output current was determined by a lack of additional force generated by increased stimulus intensity or the maximum current tolerated by the subject.

In order to avoid fatigue and ensure accuracy of 1RM values used in subsequent experimental trials, subjects completed 1RM testing for the squat and deadlift exercise on separate occasions; exercise order was allocated randomly. Testing followed the recommendations of the American College of Sports Medicine (3). In accordance with International Powerlifting Federation (26) rules, a successful squat was achieved by lowering to a depth where the hips were lower than the level of the knees before returning to the starting position. Likewise, for completion of the deadlift, subjects were required to lift the loaded barbell from the floor so that knees, hips and spine were extended, before returning the barbell to the floor in a controlled manner.

Resistance exercise

For both squat and deadlift protocols subjects warmed up with submaximal loads as follows: 8 repetitions at 55%, 6 repetitions at 65%, 4 repetitions at 75% and 2 repetitions at 85% 1RM; 3 min rest was given between warm-up sets. Subjects then rested for 5 min before completing 8 sets of 2 repetitions at 95% 1RM. A rest of 5 min was given between sets. Subjects completed the exercises using the same technique specified for 1RM testing.

Neuromuscular function

MVIC and voluntary activation (VA)

On arrival at the laboratory, electrodes for TES and EMG were applied to their respective sites. For TES, two 45 x 90 mm electrodes (Empi, Minn, USA) were placed longitudinally over the proximal vastus lateralis and distal vastus medialis muscles of the right leg (5); once attached, electrodes remained in place for the duration of the trial however all cables were removed during exercise. Subjects were then seated on a custom made isometric dynamometer so that hip and knee angles were at 90º. A seat belt was fastened around the waist and an inextensible strap secured approximately 2 cm proximal to the medial malleolus. The ankle strap was attached to an S-beam load cell (Sensortronics, USA) which provided force output into a data acquisition system (PowerLab, ADInstruments, Australia). Subjects then performed 2 x 5 s MVICs, during which force and EMG were recorded. Additionally, TES, consisting of 10 x 100 μs square wave pulses, delivered at 100 Hz, 400 V and supramaximal output current (10% greater than that established during familiarisation) (15), was applied during a sustained plateau in MVIC force (interpolated tetanic force) and 5 s post MVIC (control stimulus force). Stimuli were administered via a constant current stimulator (Digitimer DS7, Digitimer Ltd, England) controlled by Chart for Windows software (v8, ADInstruments, Australia). Each MVIC was separated by 60 s rest.

Interpolated tetanic force and control stimulus force were recorded and the greatest value from the three efforts used for analysis. VA was calculated as: VA (%) = (1-interpolated tetanic force / control stimulus force) x 100 (23). Additionally, as the control stimulus was applied to the resting muscle, i.e. absent of CNS input, the force produced was analysed separately as a measure of peripheral fatigue.

EMG

Surface EMG was sampled from the right vastus lateralis using 30 x 20 mm electrodes (Ambu Blue Sensor, Denmark) placed 20mm apart, on a line two thirds of the distance from the anterior superior iliac spine and the lateral aspect of the patella (24). A ground electrode was positioned on the patella. EMG was sampled at 1000 Hz, amplified (BioAmp, ADInstruments, Australia), filtered (10-500 Hz band pass filter) and full wave rectified

(Chart for Windows, v8). A 200 ms sample, centered on peak MVIC force was used for analysis.

Endocrine measures

Subjects were given 250 mL of water to drink and then sat at rest for 5 min. A sample of at least 2 mL was then collected by passive drooling into a polypropylene collection tube. Samples were divided into 1 mL aliquots and stored at -80 ºC until analysis. Subsequent analysis was carried out using enzyme-linked immunosorbent assay according to the manufacturer's instructions (DRG International, USA). Coefficient of variation (CV) of duplicate samples was 8.2 ± 3.2 % and 9.5 ± 2.3 % for free testosterone and cortisol, respectively.

Statistical analysis

Two-way (exercise x time) repeated measures analysis of variance (ANOVA) were performed for MVIC force, control stimulus force, VA and EMG using IBM SPSS Statistics v23 (IMB Corp. NY, USA). Data were checked for normality using the Shapiro-Wilk test. EMG, testosterone and cortisol data were not normally distributed and therefore subsequent analysis was performed after log transformation. Data were analysed as raw values and as percent change from pre-exercise values and are expressed as mean ± SD; statistical significance was set at $p < 0.05$. Where main effects or an interaction effect was observed, post hoc analysis using Bonferroni adjustment was performed. A Paired T-test was performed in Microsoft Excel 2010 to investigate differences in total volume-load, (number of sets x number of repetitions x load (kg)) (34), inclusive of warm-up sets, between exercises. Additionally, effect sizes (ES) were calculated as change in performance from baseline/baseline SD (13). Effect sizes were classified as trivial 0–0.2, small 0.2–0.6, moderate 0.6–1.2, large 1.2–2.0, and very large > 2.0 (25).

RESULTS

MVIC

MVIC force decreased over time (*p* = 0.007) however no difference was observed between exercises (*p* = 0.657). **MVIC decreased from 702.5 ± 94.7 N to 622.7 ± 118.3 N (*p* = 0.005) for the squat and from 682.8 ± 101.6 N to 622.5 ± 100.0 N (*p* = 0.006) for the deadlift, 5 min post-exercise. However, 30 min post-exercise, MVIC did not differ from pre-exercise values (squat 602.5 ± 141.0 N, *p* = 0.058; deadlift = 654.5 ± 102.0 N, *p* = 0.677).** No interaction effect was found (*p* = 0.33). Similarly, when analysed as percent change from baseline, MVIC decreased over time (*p* = 0.07, Figure 1a); no exercise (*p* = 0.119) and interaction (*p* = 0.33) effects were found. Moderate ES were found for the squat (5 min, ES = 0.84; 30 min, ES = 1.05) while deadlift only had a small effect on MVIC force (5 min, ES = 0.59; 30 min, ES = 0.28).

VA

Voluntary activation changed over time for both exercises (*p* = 0.0001, Figure 1b). The squat reduced VA from 84.50 ± 9.44% to 80.50 ± 7.47 % (ES = 0.42) and 76.15 ± 11.92 % (ES = 0.88) 5 and 30 min post-exercise, respectively. Similarly, the deadlift reduced VA from 84.55 ± 7.63 % pre-exercise, to 76.50 ± 12.21 (ES = 1.06) and 78.69 ± 12.50 % (ES = 0.78) 5 and 30 min after exercise, respectively. No difference was found between exercises (*p* = 0.765) and no interaction effect occurred (*p* = 0.171).

Control stimulus force

Force developed by the control stimulus was reduced over time (p = 0.001) however no exercise (p = 0.085) or interaction (p = 0.281) effects were found. Control stimulus force decreased from 473.1 ± 107.93 N to 401.1 ± 101.6 N (p = 0.001) and 412.0 ± 127.0 N (p = 0.039) 5 and 30 min post squat, respectively. **However, with the deadlift, control stimulus force at 5 min (451.8 ± 104.6 N, *p* = 0.326) and 30 min (479.1 ± 101.9 N, *p* = 1.00) post-exercise was not significantly different to pre-exercise values (497.9 ± 119.5 N).** When analysed as percent change from baseline, force developed by the control stimulus decreased significantly over time (p = 0.003, Figure 1c). A greater percent change in force was observed after the squat compared to the deadlift (p = 0.034), however no interaction was evident (p = 0.109). Effect sizes were trivial (deadlift 30 min, ES = 0.16) and small (squat 5 min, ES = 0.67; squat 30 min, ES = 0.57; deadlift 5 min, ES = 0.39).

EMG

EMG data showed a change over time (p = 0.048, Figure 1d) however no differences between exercises (p = 0.410) or interaction (p = 0.499) effect was found. Post hoc analysis revealed a significant difference 5 min post deadlift (- 47.9 ± 60.7 μV, p = 0.040) however no other difference over time were found (all p > 0.12). Trivial (squat 5 min, ES = 0.09; squat 30 min, ES = 0.16; deadlift 30 min, ES = 0.15) and small (deadlift 5 min, ES = 0.24) ES was calculated for changes in EMG post exercise.

Total volume-load was significantly (p = 0.0004) higher for the deadlift (5414 ± 885.8 kg) compared to the squat (4477.3 ± 654.3 kg).

Endocrine measures

Salivary cortisol was unchanged over time (p = 0.67, Figure 2a) and no difference between exercises (p = 0.27) or interaction (p = 0.15) effect was found. Similarly, salivary testosterone was not altered by either exercise (p = 0.38, Figure 2b) at either post-exercise time point (p = 0.35); no interaction effect was present (p = 0.772). Changes in testosterone were of trivial effect (all time points for both exercises, ES < 0.01 compared to pre-exercise). A moderate effect (ES = 0.79) was found for cortisol 5 min post-deadlift however all other effects were small (squat 5 min, ES = 0.17; squat 30 min, ES = -0.48; deadlift 30 min, ES= 0.33).

DISCUSSION

This study is the first to compare the acute, neuroendocrine responses of two popular compound exercises: the squat and the deadlift. The completion of 8 sets of 2 repetitions at 95% 1RM resulted in similar, significant reductions in voluntary force development (MVIC) and CNS output (VA and EMG) irrespective of exercise and the greater absolute load used and volume-load completed for the deadlift. These results, therefore, are not in agreement with the hypothesis, and popular belief, that the deadlift brings about a greater level of central fatigue than the squat. Similarly, as testosterone and cortisol were not significantly changed after either exercise, our second hypothesis, that the deadlift would produce a greater hormonal response than the squat, was not confirmed.

Few studies have used interpolated transcutaneous electrical stimulation to investigate the fatiguing effects of resistance exercise (8), with the majority relying on changes in EMG and MVIC to quantify neuromuscular fatigue and altered central drive (2, 8, 27, 35, 38, 45). The use of EMG, however, has its limitations as a means of assessing CNS output (11) therefore the use of TES, along with EMG, in this study provides valuable information about the location and magnitude of post-resistance exercise fatigue. Reductions in VA, together with a reduction in EMG, suggest that altered central drive contributed to the decrement in MVIC observed here (29). Completion of resistance exercise at loads typically used for the development of muscular strength (> 85 % 1RM) have consistently been shown to elicit acute neuromuscular fatigue (8, 17, 36, 45) which, at least in part, is caused by a reduction in the ability of the CNS to recruit and discharge motor units (44, 45). Neuromuscular fatigue has been proposed as an important stimulus for the neural adaptations and subsequent strength gains achieved through the use of heavy resistance exercise (18, 40). As such, the presence of central fatigue after both deadlift and squat exercise suggests that the protocol used here is likely to provide an adequate stimulus for neural adaptation. Anecdotally, the deadlift is assumed to create a greater level of central fatigue (39), compared to other exercises, however no empirical evidence exists to support this belief. Given the lack of difference, in VA and EMG, between the effects of the squat and deadlift, it appears that any perceived impact of the deadlift on CNS function may be attributed to other factors, rather than a greater level of acute (up to 30 mins post-exercise) central fatigue measured here. It is possible, for example, that the greater recruitment and loading of the upper back and erector spinae (22) during the deadlift leads to a prolonged and elevated perception of muscular effort in comparison to the squat. Additional research is needed to identify why the deadlift is perceived as a more fatiguing exercise.

As the force elicited by TES is representative of processes distal to the motor end plate, i.e. neuromuscular transmission and excitation contraction coupling, a decrease in force, as observed here, is indicative of peripheral fatigue (7, 29, 44). Although applied in a potentiated state, i.e. 5 s after the MVIC, decrements in force were noted in response to the applied stimulus suggesting dysfunction in one or more of the processes responsible for force production (29). Peripheral fatigue appears to be more prevalent when exercise involves a greater volume of work (45), however, in the present study, analysis of the force developed by the control stimulus revealed that a greater decrease occurred after squatting, irrespective of the fact that a greater volume-load was completed with the deadlift. We speculate that this difference in peripheral fatigue is likely the result of several factors including higher activation of the quadriceps during squatting, compared to the deadlift (12). Additionally, squatting to the parallel depth, as required in this study, may have involved a greater range of motion than performing the deadlift, which typically involves a less acute knee and hip angle at the bottom of the movement (start of the deadlift and amortization phase of the squat) compared to the squat (21). Further, the demands of the eccentric phase, and therefore time under tension, of the two exercises is likely to have been different as the squat requires a controlled lowering into the bottom of the movement while subjects were only required to return the bar to the floor in a safe and controlled manner when deadlifting. Together, the higher activation, greater range of motion and time under tension may have resulted in a larger metabolic demand, localised accumulation of metabolic by-products and subsequent, force impairment (35) within the quadriceps. However, as lactate was not measured in the present study it is unclear whether metabolic stress differed between exercises. The greater peripheral fatigue occurring after the squat suggests that the performance of exercises that rely on force development by the quadriceps are likely to be significantly impaired for at least 30 min post-squatting whereas recovery after the deadlift is considerably faster.

As with many studies investigating the fatiguing effects of resistance exercise (8, 17, 19, 35, 36), this study only investigated fatigue occurring in the quadriceps. Therefore, it is unclear whether either form of fatigue (central or peripheral) is as prevalent in the other muscles used in the two exercises. For example, it may be expected that the deadlift, which involves higher hamstring activation than the squat (12), may elicit greater levels of peripheral fatigue in this muscle group compared to the squat. Future research into the localised effects of fatigue on a range of muscles, particularly during compound exercise, would provide useful information for use in planning resistance exercise training. Additionally, this study only investigated a single loading protocol (8 sets of 2 repetitions at 95 % 1RM) and two post-exercise time points (5 and 30 min post-exercise); therefore a comparison of other load and volume combinations and time points would be informative. Of particular interest may be the accumulated, fatiguing effects of each exercise which may differ over a prolonged period of time.

In order to manipulate acute testosterone levels, current resistance exercise recommendations promote the use of large muscle group exercises, loads between 85% and 95% 1RM, moderate to high volume and short rest periods (16); therefore, given the load and muscle mass used, a change in testosterone was expected in this study. However, the absence of a significant change in testosterone, and cortisol, after squat and deadlift exercise is in line with several studies that have used high loads (>90% 1RM) (20, 38). This lack of change may be due to the relatively low volume of exercise and/or the long rest periods between sets used in the current study; cortisol production in particular appears to be strongly related to the metabolic stress created by high volume and short rest intervals (32). Whether a difference between exercises occurs when a lower load, greater volume of exercise and shorter rest period is used is currently not known. Previously, Fahey et al. (10) demonstrated that testosterone increases after completion of 5 sets of 5 RM deadlifts however this appears to be the only study to use this exercise. Therefore, along with being the first study to investigate the hormonal response to heavy (<90 % 1RM) deadlift exercise, our findings suggest that, when matched for relative intensity (% of 1RM) and rest periods, the compound exercise performed does not alter the endocrine response.

PRACTICAL APPLICATIONS

The squat and deadlift provide potent stimuli for the development of muscular strength (31) however, while the neuromuscular response to the squat is relatively well known (8, 17), the deadlift has not garnered similar interest. Although central drive was reduced after the squat and deadlift, the lack of difference between exercises raises questions about the long held, and popular, belief that the deadlift is a more centrally fatiguing exercise. As such, our results do not support the need for different periodization and tapering practices for these exercises (39). The observation that a greater peripheral fatigue occurs in the quadriceps after squatting, compared to the deadlift, can be used to help athletes, coaches and trainers plan resistance exercise to ensure optimal performance during subsequent accessory or supplementary exercise is achieved.

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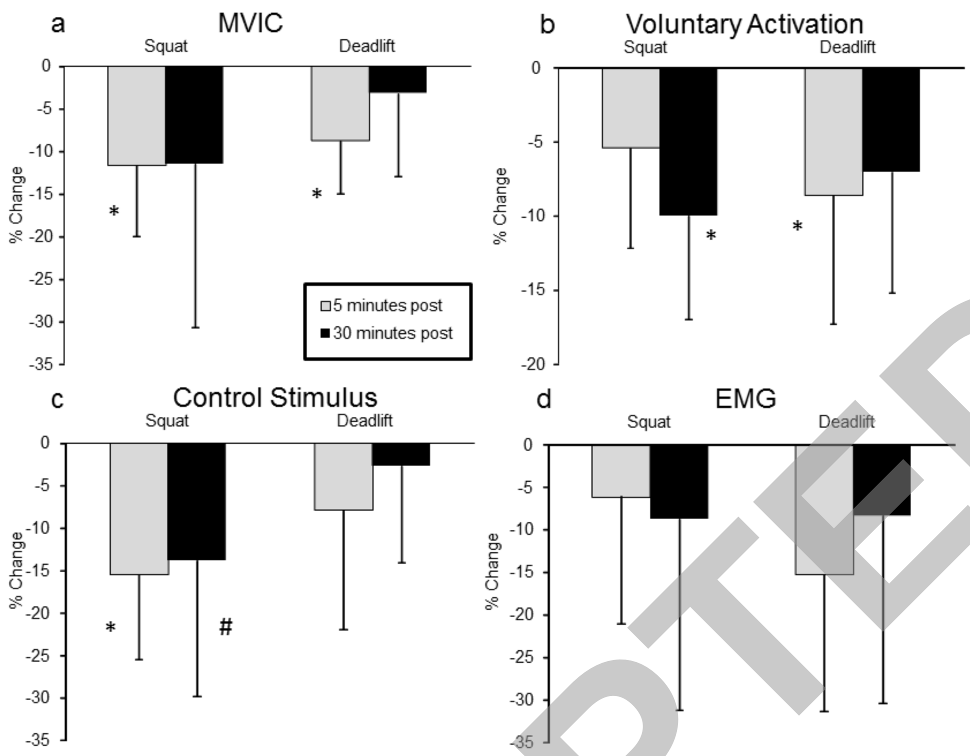
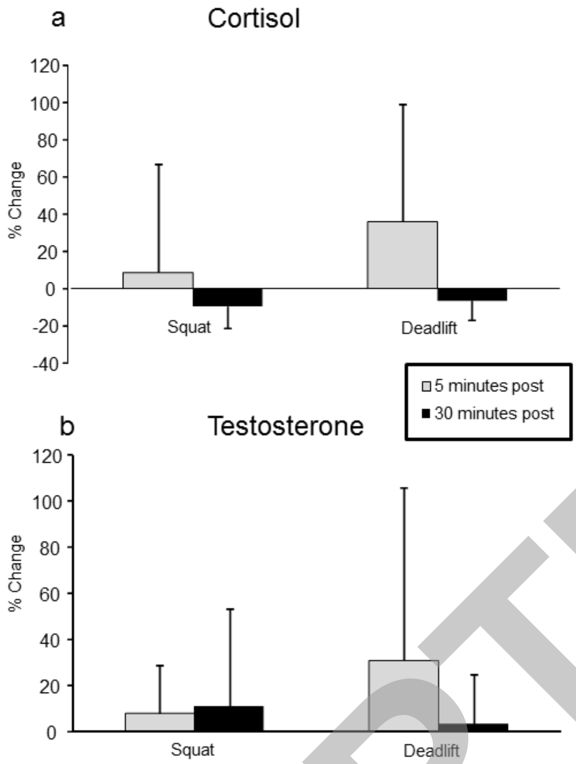
Figure 1. Percent change (mean ± SD), from pre-exercise values, measured 5 and 30 min after squat or deadlift exercise for: a) maximum voluntary isometric knee extensor force (MVIC), b) voluntary activation, c) electrically induced quadriceps force (control stimulus) and d) vastus lateralis electromyography (EMG). * denotes statistical significance from pre-exercise values $p < 0.05$, # denotes statistical significance between exercises $p < 0.05$.

Figure 2. Percent change (mean ± SD) , from pre-exercise values, measured 5 and 30 min after squat or deadlift exercise for: a) salivary cortisol and b) salivary testosterone



a
MVIC
Squat
Deadlift
% Change
5 minutes post
30 minutes post
b
Voluntary Activation
Squat
Deadlift
% Change
c
Control Stimulus
Squat
Deadlift
% Change
d
EMG
Squat
Deadlift
% Change


a
Cortisol
120
100
80
60
40
20
0
-20
-40
% Change
Squat
Deadlift
5 minutes post
30 minutes post
b
Testosterone
120
100
80
60
40
20
0
% Change
Squat
Deadlift