Muscle activation under different loading conditions during the power clean

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Muscle Activation under Different Loading Conditions during the Power Clean

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Abstract
The power clean is a component of the clean and jerk Olympic lift and is also commonly utilised in training programs for several sports. Few studies have explored electromyographical (EMG) activation of the major muscles used during this exercise. The aim of the present study was to examine muscle activation during the power clean for the following muscles: gastrocnemius (GS), vastus lateralis (VL), transversus abdominis (TA), multifidus (MU), erector spinae (ES) and trapezius (TR). Eight experienced lifters performed five maximal voluntary contraction (MVC) exercises followed by three sets of three power clean repetitions at 70%, 80% and 90% 1RM. There was a significant increase with load for peak EMG of ES and GS and mean EMG of GS and VL. This suggests that athletes targeting the ES, GS and VL in their strength training could potentially benefit by increasing intensity from 70 to 90%. There was no evidence to suggest that this intensity increase benefits the TA and MU muscles. The power clean produced significantly higher peak values than the MVC exercises for the MU and ES muscles, suggesting that it could be used as both a strength training exercise for these muscles and an MVC exercise in future studies.

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1. Introduction

Weightlifting is a popular sport worldwide, with aspects of weightlifting technique being used frequently in the training of competitive and recreational athletes, and in particular in sports that require high instantaneous power production. The power clean is a component of the clean and jerk Olympic lift, during which the bar is lifted from the ground up to the shoulder in a continuous motion. With extended elbows and a pronated grip, the power clean begins with a forceful extension through the hips and knees to lift the bar from the ground. The athlete then pulls the bar upwards until it is 'caught' on the anterior deltoids via rotation of the arms around and under the bar as the hips and knees flex into a quarter squat position (Baechle and Earle, 2008).

There is a substantial body of electromyography (EMG) research for a range of different movements. It is well established that there is a positive relationship, although not always linear, between EMG activity and muscular force (Robertson *et al.*, 2004). It has also been shown that muscular exercises can cause an increase in EMG activity and in the development of muscular strength. For example, Santtila *et al.* (2009) reported that eight weeks of strength training increased muscle force and EMG activity in the triceps brachii of soldiers.

One previous study explored EMG activity during the power clean, power snatch and their comparative Olympic versions (Hakkinen and Kauhanen, 1986). It was reported that lifting techniques changed greatly with barbell load. EMG activity of the gastrocnemius (GS), the vastus lateralis (VL), the biceps femoris and erector spinae (ES) was similar in the power clean and Olympic clean, with only minor differences between phases of the different exercises. Given the nature of the clean, it would not be unreasonable to assume that, in addition to the GS, VL, and ES, some of the other primary muscles involved are the transverses abdominis (TA), the multifidus (MU) and the trapezius (TR).

The GS assists with the transfer of force into the ground and plays an important role in plantar flexion around the ankle during the later part of the pull of the power clean, when the whole body goes into full extension. Bilodeau *et al.*(1994) noted higher EMG frequency with increased force in the GS of non-athletes during both the ramp and step increases in isometric plantar flexions.

The VL plays a key role in the extension of the knee. It is believed that this is one of the major muscles involved in the power clean technique as it generates force and momentum throughout the pull phases of the power clean and plays an eccentric role when catching the bar on the shoulders. Paoli *et al.* (2009) studied the effect of load during the back squat and found that VL activation increased with load. Increased load during the power clean is likely to elevate EMG activity of the VL in a similar way to the back squat given the similarity in movements.

The TR is thought to have a substantial role in the bar movement, particularly during the later pull phase of the clean. The middle fibres play the major role in suspension of the shoulder girdle mainly due to their size and ability to apply the necessary loads to the mechanisms formed by the scapula and clavicle (Johnson and Pandyan, 2003).

Hagberg and Hagberg (1989) reported TR EMG activity increased with load during isometric shoulder shrugs.

Trunk muscles are expected to contribute in stability and force transfer from the lower to the upper body. Previous research has shown trunk muscle activitation to increase with load (Anderson and Behm, 2005; McCook *et al.*, 2007; Nuzzo *et al.*, 2008; Willardson *et al.*, 2009). Anderson and Behm (2005) studied trunk muscle activity during the squat with stable and unstable conditions and found that ES activity increased with load. Nuzzo *et al.* (2008) reported similar results with the MU displaying progressively greater activation during 50%, 70%, and 90% of one repetition maximum (1RM) lifts. However, Willardson *et al.* (2009) found ES activity to be similar between unstable 50% 1RM and stable 75% 1RM squats, dead-lifts and overhead press. The discrepancies between studies could possibly be attributed to different methodologies or the variability of the technique used by participants during squats. McCook *et al.* (2007) found that muscle activation increased with load in the TA/IO (transverse abdominis/internal oblique) during trunk flexion and in the MU and ES during trunk extension. During maximal voluntary contraction (MVC) the EMG of antagonist muscles increased during both flexion and extension with no difference in the TA/IO during the two phases. The latter suggests that for maximal efforts the TA/IO is required to increase intra-abdominal pressure in equal amounts for movements in both directions. As the TA does not have a significant moment arm for flexion or extension (Urquhart and Hodges, 2005) it contributes to enhanced spinal stability via modulation of tension in the thoraco-lumbar fascia (Hodges *et al.*, 2005). Granata and Marras (1995) noted that co-contraction increases with movement velocity, something that may happen during the power clean and is also associated with greater intra-abdominal pressure.

Despite its popularity and frequent use in training programmes, research on the muscle activation during the power clean exercise is scarce. Thus, the purpose of this study was to examine muscle activation for different loading conditions during the power clean exercise for the following muscles: GS, VL, TA, MU, ES and TR. The loading conditions of 70%, 80% and 90% 1RM were chosen, as they reflect a range of training intensities frequently used by elite and recreational athletes.

2. Methods

Eight male participants volunteered for this study (25.1±3.2 years, 185.6±6 cm, 86.4±11.8 kg). All participants were involved in competitive sports, were free of injuries and had substantial experience in weight training (3.9±1.1 years) and the power clean (3.2±1.7 years). The protocol was approved by the institutional ethics committee and written informed consent forms were obtained before the study commenced.

Participants began with a standardised 5-minute warm-up on a cycle ergometer (Matheson *et al.*, 2001). This was followed by a range of dynamic exercises, including familiarisation with all the exercises used during the test. The sites for the electrodes were shaved and abraded with alcohol wipes. Surface EMG amplifier electrodes (SX230 1000, Biometrics, Gwent) were attached to the skin on the self-reported dominant hand side of participants following recommendations from the literature

(Seniam, 2015). EMG signal was recorded (1000 Hz) and processed through the W4X8 Datalog system (Biometrics, Gwent).

The initial MVC trial took place on an isokinetic dynamometer (Cybex Humac Norm, CSMI Medical Solutions, USA). The VL surface electrode only was attached at this time. The VL was chosen so as not to hinder the movement pattern of the power clean or damage the electrodes when the bar comes into contact with the anterior surface of the quadriceps during the clean. The electrode was placed superior to the lateral side of the patella and 66% down the line from the anterior spina iliaca. Two practice trials were followed by five seated unilateral isokinetic (contraction/contraction) knee flexion trials at a speed of 90 degrees/second (Pincivero *et al*., 1997). Range of motion stops were placed at the point where the participant's knee was at full extension and at 90º of flexion (Matheson *et al.*, 2001).

The 5 remaining electrodes were then attached to the skin of the participants. Bressel *et al*. (2011) stated that the transverse abdominis could not be isolated using surface electrodes and identified the placement as transverse abdominis/internal oblique (TA/IO). Marshall and Murphy (2003) also note the lack of a clear fascial separation of the two muscles therefore terming them as fused. Therefore in the current study the TA electrode is abbreviated as TA/IO from this point onwards.

The remaining MVC trials consisted of four sets of five-second isometric contractions interspersed with five-second relaxation periods, with 100-second rest periods between MVC trials (Matheson *et al.*, 2001; Wong and NG, 2005). The GS MVC was measured using maximal bilateral plantarflexion on a Cybex Seated Leg Press (USA) with the ankle joint remaining at 90° (Kawakami *et al*., 1998). The TA/IO MVC was measured using trunk flexion on a Life Fitness Abdominal (USA) at a hip angle of 10° (Bressel *et al*., 2011). The MU and ES MVC were measured using trunk extension on a Life Fitness Back Extension (USA) at a hip angle of 0° (vertical) ° (Bressel *et al*., 2011). Lastly, the TR MVC was measured using maximal bilateral barbell shrug with 100% of 1RM (Andersen *et al.*, 2008).

Each participant was then given a five-minute period to complete a power clean-specific warm up. A Panasonic SDR-S50 video camera (Panasonic, Indonesia) was synchronised to the EMG system through an IS2-LAD optical synchronisation cable using a start switch (Biometrics, Gwent). This allowed subsequent distinction of the beginning and end of the power clean movement. Participants then completed sets of three repetitions at 70%, 80% and 90% of their 1RM in a randomised order. The 1RM was the highest load the participant had achieved in the two months before the study. Three repetitions, rather than a single repetition, were performed for each load to provide a more accurate reflection of muscle activation. EMG signal obtained through three repetitions has been found to have very high reliability for a range of exercises (e.g. maximal or sub-maximal voluntary contractions, jump landings and cuttings) for trunk muscles, hamstrings and quadriceps (Dankaerts *et al.*, 2004; Fauth *et al.*, 2010). Three repetitions were therefore considered appropriate for the present study. Foot placement was standardised at shoulder width and hand placement at 7cm away from the inner edge of the barbell grip with a pronated hand position. Three-minute rest was provided between sets to minimise any fatigue effects (Caterisano *et al.*, 2002).

The data for all power clean sets and MVC trials was rectified and low-pass filtered with a cut-off frequency of 25 Hz. The mean and the peak EMG values of the three reps were calculated for each load. All data were normalised as a percentage of the highest EMG value recorded during either the MVC or the power clean trials.

The Shapiro-Wilk test was used to assess normality of distribution. For parametric data, a repeated measures ANOVA was used for each individual muscle to compare the three loading conditions. When sphericity was violated the Greenhouse-Geisser adjustment was applied. Post-hoc comparisons were performed to compare all pairs of load conditions and the Bonferroni adjustment was applied to eliminate the possibility of type I errors. Non-parametric data was analysed using a Friedman's ANOVA and significant differences between pairs of load conditions were explored through a Wilcoxon signed-rank test. To provide an indication of the magnitude of the differences, the effect sizes (d) for all statistically significant differences were calculated based on Cohen's suggestions, with each pooled SD being calculated as described by Field (2009). In line with Cohen's recommendations, effect sizes of a magnitude of 0.2, 0.5 and 0.8 were considered small, moderate and large respectively. For all statistical analyses significance was accepted at $p \leq 0.05$.

3. Results

The MU ($p=0.033$) and ES ($p=0.009$) had significantly higher peak values during the power clean than during the isolated MVC exercises (IME). Interestingly, the highest EMG values for the VL and TA/IO were also recorded during the power clean for all participants, although not being significantly different to those of the IME. The highest EMG values for the GS and TR were recorded during the IME and were not significantly different to those recorded during the power clean exercise.

The peak and mean EMG values are shown in Figures 1 and 2, respectively, with the statistical tests shown in Table 1. Figures 1 and 2 illustrate a trend for increased EMG with load for the GS, VL, ES and TR. However, increases in peak EMG were significant between loads for the ES and GS only. Post hoc tests for the ES peak values revealed significantly lower values with a large effect size for the 70% compared to both the 80% ($p=0.012$, $d=0.91$) and 90% loads ($p=0.027$, $d=1.08$). Post hoc tests for the GS peak values revealed significantly lower values for the 70% load than for the 90% load only ($p=0.027$, $d=0.59$).

For the mean data significant differences between loads were found for the GS and VL. Post-hoc tests for the GS revealed significantly lower values for the 70% compared to both the 80% load ($p=0.016$, $d=0.25$) and 90% loads ($p=0.016$, $d=0.64$). There was no significant difference for the VL pairwise comparisons, with just the comparison between 80% and 90% approaching significance ($p=0.074$, $d=0.35$). The average group values for the mean EMG for all muscles ranged between 20-35% of the peak values.

Table 1: Statistical Tests for Peak and Mean EMG Data

Peak EMG	p	F or χ^2	DF	Mean EMG	p	F or χ^2	DF
GS	0.030*	7.00	2	GS	0.018*	7.75	2
VL	0.079	7.50	2	VL	0.045*	3.62	1.3
TA/IO	0.416	0.94	1.2	TA/IO	0.905	0.10	2
MU	0.740	0.31	2	MU	0.895	0.11	2
ES	0.010*	9.00	2	ES	0.168	2.29	2
TR	0.199	1.82	2	TR	0.264	1.47	2

p: significance value; F *or* χ^2: test statistic; DF = degrees of freedom.
 * indicates that the 3 conditions are significantly different.

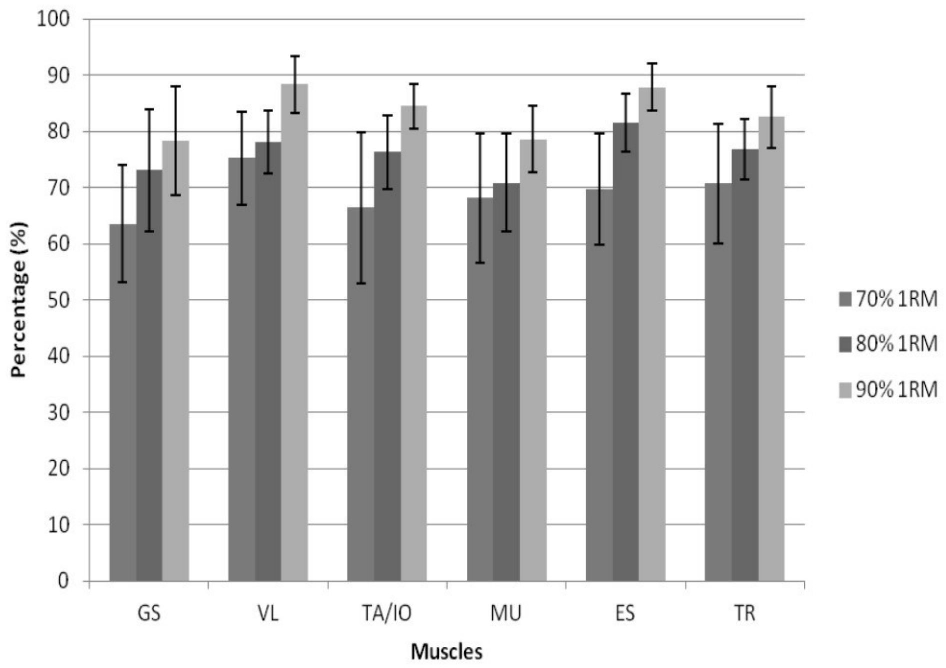

Figure 1: Peak±SD EMG amplitude (%MVC) for each muscle across the three loads.

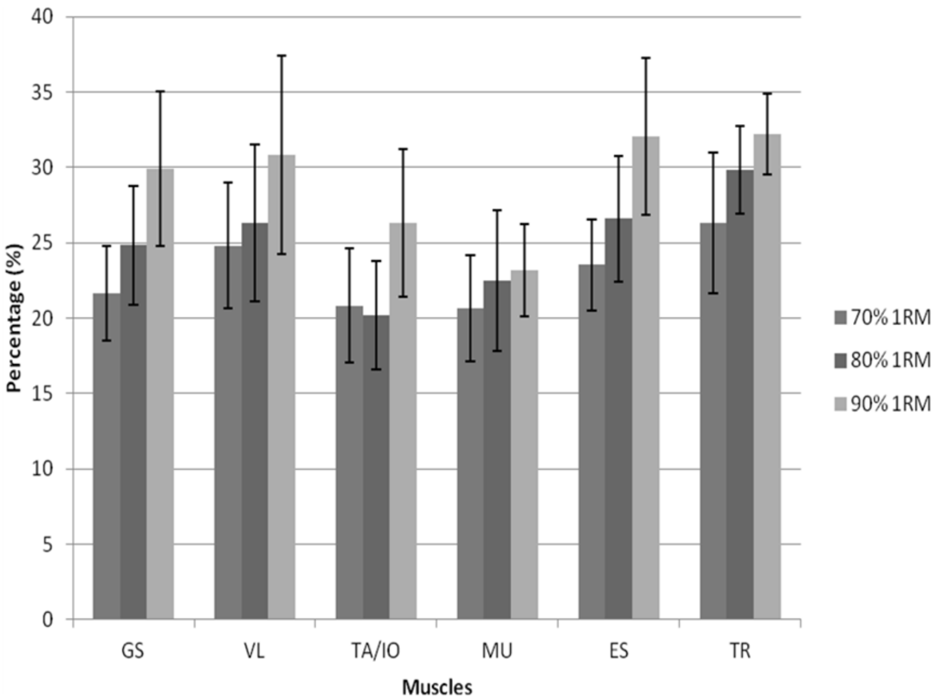

Figure 2: Mean±SD EMG amplitude (%MVC) for each muscle across the three loads.

4. Discussion

For the peak EMG values, GS activation increased between the 70% and 90% loads, with ES activation was also higher at 80% and 90% than at the 70% load. The latter is in agreement with previous studies suggesting that loads greater than 75% 1RM elicit increased ES activation (e.g. Willardson *et al.*, 2009). As these were the only significant differences in peak values, it could be suggested that when producing the extra force and stability required to lift heavier loads, the ES and GS seem to be the main muscle groups that require increased peak activation. Interestingly, despite the difference in the peak ES values, the increase in the mean ES values was not significantly different between loading conditions. This suggests that with increased load there is higher EMG activity in some phases of the lift, but seems to be poorly maintained throughout the muscle's range of motion. To further our understanding with respect to when such increases may occur, future studies could perhaps split the power clean into different phases and calculate the EMG values for each phase.

The mean EMG values showed a significant increase with load for the GS and VL. GS activity was higher at the 80% and 90% than the 70% load. The main role of the GS is to plantar flex the ankle during the later pull phase of the power clean. If at this point enough force is generated from the quadriceps and shoulder muscles it could be the case that the GS may not need to be fully activated. This is particularly true with a lower load and may explain the increase from the 70% 1RM to the heavier lifting conditions. The mean VL data suggest that with increased load participants rely more heavily on the ability of the VL (and possibly the rest of the quadriceps group) throughout the lift. Despite the overall loading effect, the differences between each pair of loads did not reach significance. This could perhaps be linked to the range of loads selected for this study. For example, Paoli *et al.* (2009) did find significant differences between loads in the VL when comparing a wider range of back squat loads that included loading of 30% and 70% 1RM.

In addition to the above significant differences, there was a trend for EMG increase with load for the TR. Given the sample size and the range of loads, it is possible that if more participants or a wider range of loads are used then significant differences may be found in the TR as well as in other muscles. With the present study prioritising the six muscles tested and considering the limitations of wired EMG and the restriction of movement which can occur when electrodes are attached to participants, it was decided not to collect data on any other muscles. It is however recommended that in future studies the EMG activity of other muscles that may also play an important role in the power clean is included, such as the hamstrings and the gluteus maximus.

To further improve our understanding of the EMG patterns during the power clean in the present study, it was decided to explore the SD of the data. There were no significant differences in the SD of mean EMG. However the SD of peak EMG seemed to decrease with increased load in all muscles, with the TR value being statistically significant ($p=0.047$). This trend is unsurprising given the variable nature of lifting technique especially at lower loads (Garhammer *et al.*, 1998). The TA/IO and MU, two deep trunk muscles which are considered part of the local stabilizing system (Anderson and Behm, 2005), had the largest SD values. This reinforces evidence that trunk muscles do not always use the same strategy to create trunk stability (Westad *et al.*, 2010). Overall, heavier loads seemed to produce more consistent peak EMG activity, which could have important practical applications when between-participant consistency of peak muscle activation is of interest. However, the influence that mean EMG activity has comparatively to peak EMG activity is still unclear and warrants further investigation.

The peak EMG values were significantly greater during the power clean than the IME in the MU and ES muscles, with a similar but non-significant trend for VL and TA/IO. It is therefore evident that participants were not reaching maximum EMG during the MVC exercises, a phenomenon previously noted by others (Soderberg and Knutsen, 2000). It could be the case that during dynamic movements a greater amount of muscle mass is present under the electrode site than during MVC exercises, or that differences in muscle length under isometric and dynamic conditions cause greater EMG activity during dynamic movements.

Although not uncommon to obtain high peak EMG during near to maximum dynamic exercises, these findings further emphasise the importance of identifying appropriate MVC exercises that would elicit the highest EMG activation. To that respect, the present findings have another important practical application. With the power clean exercise producing significantly higher peak EMG activity in the MU and ES than during participants' perceived maximal effort in exercises previously recommended in the literature, it can be suggested that the power clean can be used in future EMG studies for quantification of maximal values for the MU and ES. Moreover, it has been suggested that high levels of neuromuscular activation (normally over 60% MVC) over prolonged periods of time yield muscle hypertrophy and gains in muscle strength

(Andersen *et al.*, 2006). This suggests that the power clean could be used as a strength training exercise MU and ES. In the present study the highest EMG values for ES and MU during the power clean were recorded during the 90% 1RM lifts, which suggests that 90% 1RM would be an appropriate loading for the purposes described above. Given the statistically significant increases with load for the ES, it would not be unreasonable to assume that power clean repetitions higher that 90% could produce even higher EMG values. This could have an impact on athlete practice as exercises designed to improve strength in these muscles in an isolated manner may be unnecessary to elicit improved strength. Despite the differences between the power clean and the IME for the VL and TA/IO muscles not being significant, the higher values recorded during the power clean imply that the power clean could also be added to or utilized to a greater extent in strength training programmes and used as an alternative/additional MVC exercise for these muscles.

5. Conclusions and practical applications

During the power clean EMG activity increased with load primarily for the ES, GS and VL muscles. This suggests that when athletes attempt to increase lifting loads from 70 to 90%, key neural adaptations such as increased recruitment of the motor unit pool and greater synchronisation would be evident in these muscle groups. It also suggests that when athletes target these muscle groups in training they could potentially benefit by increasing intensity from 70 to 90%. There was no evidence to suggest that this increase in intensity would be of any additional benefit to the MU and TA/IO muscles though. Nevertheless, these muscles also produced high EMG values during the power clean, which were also higher than the MVC exercise, which suggests that utilising the power clean in a training programme could have beneficial effects on the strength development of these muscle groups as well. Finally, with higher peak EMG values observed during the power clean than for the MVC for the ES and VL, it is suggested that the power clean could be considered as an alternative MVC exercise for these muscle groups in future EMG studies.

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