The Effect of Fatigue on Lower Extremity Electromyography During Clean Performance in Elite Female Weightlifters

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ABSTRACT

THE EFFECT OF FATIGUE ON LOWER EXTREMITY ELECTROMYOGRAPHY DURING CLEAN PERFORMANCE IN ELITE FEMALE WEIGHTLIFTERS

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The clean is a primary movement in the sport of Olympic weightlifting. Management of fatigue is essential to optimizing weightlifting performance. The purpose of this study was to examine the effects of fatigue on EMG activation during clean performance in elite female weightlifters. Electromyography (EMG) data was collected bilaterally from the vastus lateralis (VM) and vastus lateralis (VL) during maximum voluntary isometric contraction (MVIC) and clean trials. Muscle activity was collected during pre- and post-fatigue clean trials at 60%, 70%, and 80% of the subject’s self-reported one repetition maximum (1RM). Subjects completed a fatiguing protocol consisting of two sets of front squats until failure at 80% 1RM. The results showed a significant decrease in EMG activation between 70% and 80% 1RM for the left VL. We found no significant differences between pre- and post-fatigue EMG activity across the measured muscles. This study provides information regarding the fatigue resistance of elite female weightlifters.
THE EFFECT OF FATIGUE ON LOWER EXTREMITY ELECTROMYOGRAPHY DURING
CLEAN PERFORMANCE IN ELITE FEMALE WEIGHTLIFTERS

BY

JOHN A. LITTNER
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Thesis Director:
Christopher M. Hill, PhD
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CHAPTER 1
INTRODUCTION

The clean and snatch movements were first introduced to the Olympic Games in 1896. Upon first introduction the sport was a male-only event. It was not until 2000 that a female event was created to make the highest level of competition available for everyone (Moore & Quintero, 2019). Accounting for the addition of the Olympic female event and the increased popularity of CrossFit, the popularity of the sport of weightlifting has increased approximately 70% in the last twenty years (Moore & Quintero, 2019). As popularity has increased, these movements have become common practice in strength and conditioning programs.

Cleans are among the top exercise choices for increasing power output. While squat and deadlift typically make up the basis for exercise selection in sports performance training, the exercises do not train power development like the Olympic movements (Garhammer, 1993). Management of fatigue in the weight room is one of the most important roles of a strength and conditioning coach. Understanding how fatigue develops and when to implement blocks of training that cause high fatigue is the basis of periodization (Favero & White, 2018). This understanding helps the coach reduce the risk of injury and maximize performance (Haff & Triplett, 2015). The role of fatigue on muscle activity and performance of the squat and deadlift is well documented (Barnes et al., 2019). Barnes et al. (2019) investigated the relationship between fatigue and two powerlifting movements, the squat and deadlift. Electromyographic (EMG) amplitude decreased in muscles of the lower extremity for both movements, and they also demonstrated the practicality of monitoring fatigue with EMG in a strength and conditioning
setting. However, there is a gap in the literature regarding the relationship between a dynamic movement like the clean and fatigue. Further research must be conducted to understand this relationship and the feasibility of monitoring dynamic movements in a strength and conditioning setting. The purpose of this study was to determine the effects of fatigue on clean performance in elite female Olympic weightlifters. We monitored muscle activation during clean movements before and after a fatiguing protocol. We expected muscle activation to increase after participants completed the fatiguing protocol.
CHAPTER 2
LITERATURE REVIEW

2.1 Overview of Electromyography (EMG) and Fatigue

Fatigue is defined as the inability to continue producing required force during a particular task (Edwards, 1983). Quantifying muscular fatigue is as complex as the phenomenon itself and multiple methods have been employed to gauge fatigue magnitude. The most common method to evaluate fatigue is by force transducers or isokinetic dynamometers, which evaluate changes in muscle torque (Dimitrova & Dimitrov, 2003), followed closely by surface electromyography (EMG), a noninvasive method of collecting electrical muscle activity (Camic et al., 2014). The correlation of the myoelectric signal with muscle fatigue has been well documented (Kamen & Gabriel, 2009). Fatiguing muscular EMG signal displays changes in amplitude and frequency compared to resting muscles (Basmajian et al., 1985), which result from decreases in motor unit firing rate, neuromuscular propagation failure, or reduced conduction velocity (Basmajian et al., 1985; Camic et al., 2014; Kamen & Gabriel, 2009). The reason behind the changes in muscle properties has been attributed to central and peripheral mechanisms (Babault et al., 2006; Enoka and Stuart, 1992). One example of a peripheral mechanism that contributes to the slowing of conduction velocity is increased concentrations of K⁺ ions and the lack of Na⁺ within the muscle fiber (Kamen & Gabriel, 2009). A 2014 study (Camic et al., 2014) examined the response of torque, EMG amplitude, and EMG frequency to 30 repeated maximal eccentric muscle actions in females. Results showed a decrease in mean torque and EMG frequency, and no change was found for EMG amplitude. These results
indicate torque and EMG frequency will decrease as fatigue from repeated maximal eccentric muscle actions increases. The authors suggest the observed eccentric fatigue is accredited to mechanical failure rather than metabolic changes that would typically be observed during an isometric or concentric contraction (Camic et al., 2014).

Hautier et al., (2000) observed changes in EMG during repeated maximal sprints on a cycle ergometer. Ten subjects performed a series of sprints with EMG electrodes monitoring the gluteus maximus, rectus femoris, vastus lateralis, gastrocnemius lateralis, and biceps femoris muscles. The data showed a significant decrease in maximal power output and cycling rate from the first sprint to the thirteenth. Muscles associated with knee flexion had a significantly lower EMG signal by the thirteenth sprint. This data shows that maximal-intensity cycling induces fatigue in these lower extremity muscles. The authors explain that fatigue begins to present due to decreased efficiency of the EMG signal. This decrease could be attributed to lactate accumulation, contractile loss of power from high-output muscles, or the depletion of high-energy phosphates (Hautier et al., 2000).

Bilodeau et al. (2003) compared fatigue effects on EMG signal in males and females. The authors observed the percent maximum voluntary contraction (MVC) response of the quadriceps muscle group to a gradual ramp-up maximum isometric knee extension fatiguing protocol. Root mean square (RMS) amplitude, mean power frequency (MPF), and median frequency (MF) changed across all three muscles observed (rectus femoris, vastus lateralis, vastus medius). Males had a higher, but not significant, EMG RMS during pre-fatigue MVC compared to females, which was attributed to differences in muscle size between the two groups. However, there was no significant differences between males and females in EMG RMS, MPF,
or MF during the fatiguing protocol. Overall, these findings may suggest males and females have a similar response during the fatiguing protocol as well as during the post-fatigue test.

### 2.2 Overview of Clean Movements

A clean in its simplest form involves moving a barbell from the floor to the shoulders in one fluid movement (Haff & Triplett, 2015). High power output separates the Olympic movements from general squatting or deadlifting (Garhammer, 1993). Properly and efficiently performing this movement requires strength, proprioception, coordination, and timing, among other qualities. Coaches and athletes spend years attempting to master the technical aspect of the clean. Some coaches estimate completion of a minimum of 10,000 repetitions before a complete understanding of the movement can be achieved. Synchronization of joint and muscles movements is a determining factor in the development of a weightlifter and is an essential component of maximizing power output and athletic potential (Haff & Triplett, 2015).

The goal of the sport of weightlifting is to lift maximal weight within the rules of each lift. These rules cause weightlifters to follow the same technical progression to complete each lift (Kipp et al., 2012). The clean movement can be broken down into detailed phases, which are depicted in Figure 1. The National Strength and Conditioning Association (2016) highlights four main phases of movement for each lift. The first pull signals the beginning of the lift as the bar moves off the floor due to the lifter pushing their legs. During this phase it is important the trunk angle of the lifter remains unchanged (Kipp et al., 2012). As the bar approaches the knee, the transition phase begins. This phase bridges the gap between the first and second pulls. The bar will pass the knees, which flex slightly as the bar elevates. Holding a constant back angle reduces hip extension during the first pull and the transition phase. Kipp et al. (2012) found
greater lift mass is associated with less hip extension during those phases. With the bar above
the knees, the second pull begins. The bar will begin accelerating as the hips, knees, and ankles
all move toward full extension. A greater knee extension moment and rapid hip extension during
the second pull is critical for maximizing lift mass (Kipp et al., 2012). As these joints extend, the
shoulders will violently shrug to direct the bar vertically. As the bar begins to move toward the
shoulders, the second pull ends and the catch phase starts. The lifter will now rapidly descend
under the bar to meet it at its highest point. In a clean, the lifter will catch the bar and ride it
down into a front squat, but in a power clean, the lifter will stop the bar at the first point of
contact rather than squat (National Strength and Conditioning Association, 2016).

2.3 Electromyography of Clean Movements

A clean involves moving the bar from the floor to the shoulders by utilizing a pull and
catching the bar in a full front squat. A power clean involves a similar process, except the lifter
must catch the barbell before the femur reaches parallel with the floor. The power clean is often
used because it requires more power generation to drive the bar high enough to catch above
parallel. Dryburgh and Psycharakis (2016) utilized the power clean to examine muscle activity
at varying percentages of 1RM (70%, 80%, and 90% 1RM) for each participant. EMG data was
Figure 1: Images from left to right of each technical position of a power clean. 1 first pull, 2 transition phase, 3 second pull start, 4 second pull end, 5 catch phase, 6 completed lift. Source: National Strength and Conditioning Association (2016).
collected from multiple muscles of the lower extremity (gastrocnemius, vastus lateralis, biceps femoris, and erector spinae) and compared to the individual’s maximum voluntary isometric contraction (MVIC). They found both the erector spinae and gastrocnemius muscles significantly increased activation with the increased load. Muscle activity of the vastus lateralis indicated potential reliance on the quadricep muscles to meet the increased demand from higher loads. This study demonstrates the necessity of the quadriceps muscle group to perform a related exercise to the clean, like a power clean. It also shows the increase in muscle activity with increased load but does not address the impact of fatigue on muscle activity.

Santos et al. (2021) also examined EMG activity during Olympic-style weightlifting. This study used EMG data to assess muscle synergy in experienced and novice weightlifters. These individuals completed a power clean 5RM test for analysis. They found large average EMG values for the following lower extremity muscles: gluteus maximus, biceps femoris, vastus lateralis, semi tendinosis, and lateral gastrocnemius. Inexperienced individuals used similar muscular coordination patterns to complete the lift similar to experienced lifters. This data shows that activation of these muscles is important to performance in the clean. Though, unexperienced individuals used muscular coordination patterns to complete the lift similar to experienced lifters, the magnitude of activation was higher in the experienced group. The authors suggest inexperienced lifters try to mimic the technique of experienced lifters, such as delayed hip extension and upper limb flexion, to gain the same benefits from the muscle activation patterns (Santos et al., 2021).

2.4 Fatigue in Weightlifting Exercises

There is a severe lack of literature investigating the relationship between fatigue and Olympic weightlifting performance. However, other studies have demonstrated EMG responds
to increasing levels of fatigue in other weightlifting styles (i.e., powerlifting; Barnes et al., 2019; Dryburgh & Psycharakis, 2016; Santos et al., 2021). For instance, Barnes et al. (2019) examined the effects of neuromuscular fatigue on the squat and deadlift movements. Subjects were measured for MVIC, one repetition maximum (1RM), and completed a testing protocol for each lift working up to 95% 1RM. Their analysis showed a decrease, not significant, in EMG activation of the lower extremity for both the squat and deadlift movements. Deadlift EMG decreased about 15% in the vastus lateralis, compared to about 5% for squat. This difference was attributed to the significantly higher load in the deadlift movement. Moreover, their study demonstrated the feasibility of monitoring fatigue in a strength and conditioning setting.

Another area of interest is the response of EMG signal to training at different velocities. Collison (2017) investigated EMG changes to fatigue because of either fast-tempo (FT) or slow-tempo (ST) training. Subjects completed FT and ST repetitions of a hexagonal-barbell deadlift. The author found decreased MVC torque values for both FT and ST, with ST decreasing slightly more. These findings were followed by decreases in potentiated twitch torque and voluntary activation, which indicated decreases in contractile function and motor neuron recruitment (i.e. fatigue). This study shows the impact of tempo-based resistance training on performance and fatigue.

Taking the previous findings together, there is a dearth in the literature regarding the nature of fatigue during Olympic weightlifting and how different forms of clean, which change lift velocity, are affected by fatigue. Thusly further research is needed to investigate the role of fatigue in elite female weightlifters during the Olympic lifts with EMG monitoring (Garhammer, 1993).
CHAPTER 3

METHODOLOGY

3.1 Participants

Twelve elite female weightlifters (mean age: 25.3 ± 5.3 years), mean height: 163.4 ± 5.2 cm, mean weight: 75.0 ± 13.4 kg) participated in this study. Inclusion requirements included a minimum of one year of regular (3 sessions per week minimum) Olympic weightlifting training, which includes clean exercises, and free of a current diagnosis or history of neurological, cardiovascular, or musculoskeletal diseases.

3.2 Instrumentation

Surface electromyography (EMG) was collected using Delsys wearable EMG sensors (Delsys Incorporated, Natick, MA, USA) with a sampling frequency of 2000 Hz. Muscle activity was assessed bilaterally from knee extensors (vastus medialis [VM], vastus lateralis [VL]). A Humac Norm isokinetic dynamometer (Computer Sports Medicine Inc., Stoughton, MA, USA) was used to collect maximum voluntary isometric contraction data.

3.3 Experimental Procedures

The study utilized a within-subjects repeated measures design in which all participants executed the clean procedures under two conditions (Pre-Fatigue, Post-Fatigue). Informed consent (Appendix A) and the Physical Activity Readiness Questionnaire (PAR-Q; Appendix B) were provided to all participants to read and sign.

This study consisted of one testing session. At this meeting, participants received an overview of the experimental procedure and completed the health history screening using the
PAR-Q. Next, the skin was shaved, abraded, and cleaned with an alcohol pad before attaching the EMG electrodes on the muscle belly of the above-described muscles. Placement of electrodes was determined according to the guidelines laid out in the SENIAM Project (Hermens et al., 1999). Participants were then fitted to the isokinetic dynamometer where they were required to complete a warmup consisting of five isometric, five concentric, and five eccentric contractions. Prior to starting the warmup, the seat of the isokinetic dynamometer was adjusted for their comfort and limb length. These settings were recorded for consistency throughout testing. These contractions were set to a low intensity around 50% of maximal intensity. The dynamometer was standardized to a relative joint angle of 120 degrees between the thigh and knee for isometric contractions. Concentric and eccentric contractions were executed at a standardized angular speed of 30 degrees per second. Range of motion was also standardized to 90 degrees. Five seconds of rest occurred between each repetition. Subjects rested for 1 minute after completing each contraction type. Following warmup, the subject completed three maximum voluntary isometric contractions (MVIC). As in the warmup, relative joint angle was standardized to 120 degrees. Each isometric contraction was held for 3 seconds (Camic et al., 2014).

Following collection of MVIC data, participants began preparation for clean data collection. The participant took three warmup lifts to work up to 50% 1RM. The participants performed three counterbalanced cleans at 60%, 70% and 80% 1RM. Percent 1RM values were determined based on standard attempts taken during training for these lifters. A 3-minute seated rest period was provided between each lift.

Next, participants completed the fatiguing protocol. The participant completed two sets of front squats until failure. For this study failure was considered the inability to complete a
repetition without assistance. Front squat repetitions were completed at 80% of the subject’s clean 1 RM. Following the fatiguing protocol, participants repeated the above clean procedure.

3.4 Data Analysis

The raw EMG data was filtered using a bandpass filter of 20-250 Hz and full-wave rectification was performed before exporting for analysis. Mean EMG data for all four muscles was calculated for each MVIC trial. An overall mean for each muscle was derived across the three MVIC trials. This value was used to normalize the muscle activation during the clean trials. Mean root mean squared (RMS) and peak EMG values were derived for each clean trial from the normalized EMG waveform.

3.5 Statistical Analysis

EMG dependent variables for MVIC and clean trials were analyzed using a 2 x 3[2 Fatigue (Pre-Fatigue, Post-Fatigue) x Percent 1RM (60%, 70%, 80%)] repeated measures analysis of variance. Analysis was conducted for the left vastus lateralis (LVL), right vastus lateralis (RVL), left vastus medialis (LVM), and right vastus medialis (RVM). Post hoc analysis was completed to further examine p values less than 0.05. All analysis had an alpha level set at 0.05 and was conducted in JASP 0.14.1.
CHAPTER 4

RESULTS

4.1 Peak Muscle Activity

Weightlifters decreased peak EMG activity with increases in percent 1RM ($F(2, 1.598) = 3.780, p = 0.039, \eta_p^2 = 0.256$). A significant difference was found in LVL peak EMG activity between 70% and 80% 1RM ($t = 2.747, p = 0.035, \text{Cohen’s } d = 0.450$) as reflected in Figure 2. However, 60% was not significantly different compared to 70% ($t = -1.271, p = 0.308, \text{Cohen’s } d = -0.208$) or 80% 1RM ($t = 1.476, p = 0.308, \text{Cohen’s } d = 0.242$). These differences were not reflected in fatigue main effect ($F(1, 11) = 1.113, p = 0.314, \eta_p^2 = 0.092$) (Figure C1).

Percent 1RM main effect in the remaining muscles did not reflect the results of the LVL. No significant difference was found in percent 1RM for RVL ($F(2, 1.282) = 0.678, p = 0.518, \eta_p^2 = 0.058$) (Figure C3), LVM ($F(2, 1.150) = 1.218, p = 0.315, \eta_p^2 = 0.100$) (Figure C2), or RVM ($F(2, 1.663) = 1.310, p = 0.290, \eta_p^2 = 0.106$) (Figure 3). The results of pre- and post-fatigue peak EMG activity were similar to the percent 1RM results. No fatigue main effect significant difference was found for RVL ($F(1, 11) = 0.265, p = 0.617, \eta_p^2 = 0.024$), LVM ($F(1, 11) = 2.285, p = 0.159, \eta_p^2 = 0.172$), or RVM ($F(1, 11) = 0.745, p = 0.406, \eta_p^2 = 0.063$).

4.2 Mean Muscle Activity

Mean EMG activity was calculated for clean repetitions at 60%, 70%, and 80% of 1RM in these elite weightlifters. No significant difference was found in main effect percent 1RM for LVL ($F(2, 1.954) = 2.066, p = 0.151, \eta_p^2 = 0.158$) (Figure C5), RVL ($F(2, 1.452) = 0.1568$,
p = 0.231, \eta^2_p = 0.125) (Figure 4), LVM (F(2, 1.693) = 1.623, p = 0.220, \eta^2_p = 0.129) (Figure 5),
or RVM (F(2, 1.556) = 2.343, p = 0.120, \eta^2_p = 0.176) (Figure C4). Mean EMG activity was also
calculated for both pre- and post-fatigue conditions. No significant difference was found in main
effect for fatigue conditions in the LVL (F(1,11) = 1.294, p = 0.279, \eta^2_p = 0.105), RVL (F(1,11)
= 0.968, p = 0.346, \eta^2_p = 0.081), LVM (F(1,11) = 0.333, p = 0.575, \eta^2_p = 0.029), or RVM
(F(1,11) = 0.585, p = 0.460, \eta^2_p = 0.051).

4.3 Front Squat Repetitions

Subjects were required to complete two sets of front squats to failure with 3 minutes rest
in between. The results from the pre-fatigue set (mean repetitions = 13.8 ± 4.8) and the post-
fatigue set (mean repetitions = 10.9 ± 2.8) indicate the completion of the first set resulted in a
significant decrease in repetitions in the second set (t(11) = 2.864, p = 0.008, Cohen’s d = 0.827)
(Figure 6).

Figure 2: Left vastus lateralis percent 1RM across peak EMG activation relative to
measured MVIC. (*p value < 0.05)
Figure 3: Right vastus medialis pre- and post-fatigue conditions across peak EMG activation relative to measured MVIC at given percentages of 1RM.

Figure 4: Right vastus lateralis pre- and post-fatigue conditions across mean EMG activation relative to measured MVIC at given percentages of 1RM.
**Figure 5:** Left vastus medialis pre- and post-fatigue conditions across mean EMG activation relative to measured MVIC at given percentages of 1RM.

**Figure 6:** Mean front squat repetitions from set 1 and set 2 of the fatiguing protocol. (*p value < 0.05)
CHAPTER 5

DISCUSSION

The goal of this project was to examine the effects of fatigue on clean performance in elite female Olympic weightlifters. We evaluated each weightlifter on MVIC, pre- and post-fatigue peak and mean muscle activity. We found a significant difference in lower extremity peak muscle activation between 70% and 80% 1RM for the left vastus lateralis. There was no significant difference between percent 1RM in the LVM, RVL, and RVM. No significant difference was found examining fatigue main effects and fatigue x percent 1RM interactions. We hypothesized that EMG muscle activation would increase post-fatigue compared to pre-fatigue and increase with intensity. The results of this study did not support the hypothesis and indicate that further research is needed to fully understand the relationship between fatigue, intensity, and clean performance in elite weightlifting athletes.

5.1 Percent 1-Repetition Maximum Increased Muscle Activation

Peak LVL muscle activation significantly decreased between 70% and 80% 1RM. This significant decrease could be attributed to technical execution of the clean itself. As loads increase, lifters may change their technique to apply more force to the bar (Kipp & Meinerz, 2017). In Kipp and Meinerz’s (2017) assessment of successful and unsuccessful clean attempts, they found that the final height of the bar is a determining factor for the success of the lift. To execute a clean, the bar must have vertical force applied to it to allow the lifter to receive the barbell prior to descending into a front squat motion (National Strength and Conditioning Association, 2016). One way the lifter might attempt this is by increasing the speed at which they
descend under the bar. When this happens, the lifter will often stop applying force to the bar earlier in the lift to begin descent. This change in technique can be detrimental to the success rate of the lift (Kipp & Meinerz, 2017). Pairing this knowledge with our current findings would suggest our lifters changed their technique going from 70% to 80% corresponding with the higher load. As a result, peak muscle activation would then be lower compared to completion of the lift with the individual’s normal technique, which was performed at the other loads.

An increase in muscle activation was found from 60% to 70% IRM; however, it was not significantly different. This finding points to a similar strategy being utilized during the two workloads. Interestingly, 60% and 80% did not demonstrate differences in activation, which may suggest that the new strategies employed by the participants is similar to that used at lower loads. However, this is speculative and requires further investigation with the usage of kinematics assessment.

5.2 Fatigue Did Not Affect Muscle Activation During Clean Performance

Fatigue management is a basic principle of periodization (Favero & White, 2018). Understanding the relationship between fatigue and performance is essential to constructing a program for optimal performance, especially for elite competitive weightlifting. Hence, fatigue was one of the primary topics of emphasis for this study. For this study, we accessed muscle activation before and after two sets of front squats at 80% clean 1RM until failure to stimulate fatigue in the lower extremity. We found no significant differences in pre- and post-fatigue measurement across the measured muscles of the lower extremity. These results may be partially attributed to the selected population of elite female weightlifters. Walker et al. (2013) examined the effects of long-term resistance training on fatigue resistance over the course of 20 weeks. They found subjects who performed resistance training demonstrated increased fatigue
resistance compared to a control group. The participants in this study were females with a minimum of one year of regular (3 sessions per week minimum) Olympic weightlifting training, which is similar to the type of exercises performed in Walker et al. (2013). It can then be concluded, due to high workload in these dynamic movements, the participants from this study likely have a higher than normal work capacity and therefore are more resistant to acute fatigue induced by the sets of front squats.

As mentioned above, it is possible the fatigue protocol used in this study was not intense enough to thoroughly fatigue these lifters. Previous studies have noted differences in lower extremity muscle activity when comparing acute and longitudinal fatigue (Yaggie & McGregor, 2002; Yaggie & Armstrong, 2004; Dickin & Doan, 2008). This study utilized a short acute fatiguing protocol in the form of front squats until failure and found no differences in muscle activity. These findings suggest that the acute protocol was not suitable for inducing changes in the neuromuscular function of the lower extremity. A protocol resembling more closely a full training session with movements more directly related to the clean could be an effective way to promote fatigue build-up, opposed to the acute protocol. Further research using a clean-based fatiguing protocol or more long-term fatiguing protocol is necessary.

Another important aspect that may contribute to the overall findings was time between repetitions of the performed cleans. This study utilized a rest interval of 3 minutes between clean repetitions, which was based on a previous study in a similar domain (Haff et al., 2003; Hardee et al., 2012). A repetition in weightlifting is completed within a few seconds. During activity lasting less than 10 seconds, the primary energy system used is the ATP-PCr system (McMahon & Jenkins, 2002). This system is a high-power but low-capacity system the body can use to make energy during exercise (Zuniga et al., 2012). Three to five minutes of rest is needed
between bouts of high-intensity exercise for this system to fully resynthesize phosphagen stores (Bender, 2019; Tomlin & Wenger, 2001). The 3-minute rest interval used in this study allowed the ATP-PCr system to effectively recover, thus minimizing any effects the fatigue protocol had on clean performance.

5.3 Limitations

While this study shows how clean performance can be affected by intensity, there are limitations that should be considered. First, the sample size of this study did not meet the suggested size according to our statistical power analysis ($\beta=0.8$, medium effect size, $n=34$). While this could be considered an undersized sample size, it is similar to sample sizes of previous studies (Dryburgh & Psycharakis, 2016, $n=8$; Kipp et al., 2012, $n=10$; Kipp & Meinerz, 2017, $n=15$). Related to sample size, data collection for this study took place during the COVID-19 pandemic. Multiple potential subjects were ruled out due to contraction of the virus within the testing window. Another possible limitation is the fatigue protocol used in this study. As mentioned, the rest intervals might have been too long, allowing for too much recovery in between sets. The protocol could be altered to use clean movements to fatigue the lifter opposed to front squats. This change could align the mechanism of fatigue with the movement of interest for the study.

5.4 Conclusions

Peak muscle activation of the LVL significantly decreased between 70% and 80% 1RM in elite female weightlifters. Despite implementation of a fatiguing protocol, no significant main effect differences were found in percent 1RM and fatigue for the remaining muscles. The results of this study highlight the fatigue resistance of these elite weightlifters. Managing fatigue is a key concept of periodization, especially in the sport of weightlifting. This information could be
used to design a periodized program with sufficient intensity and volume to either properly
fatigue elite weightlifters or prepare them for optimal performance. Future studies could
examine the effect of a more intense fatiguing protocol with shorter rest intervals on clean
performance.
REFERENCES


Northern Illinois University

CONSENT FORM

Title: The effect of fatigue on lower extremity electromyography during clean and power clean performance

Principal Investigator
Christopher M. Hill
Department of Kinesiology and Physical Education
Anderson Hall
Northern Illinois University
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Key Information
- This is a voluntary research study about how fatigue effects clean and power clean weight lifting performance.
- This study will be conducted in one testing session, lasting 1 hour and 15 minutes.
- The benefits include the satisfaction of learning and participating in a biomechanical research study. The risks include muscular soreness due to the movements from exercise and the fatigue protocol.
- All local and state COVID-19 procedures and policies will be followed by the researchers throughout your participation in this research study.

The purpose of this study
Cleans and power cleans are among the top exercise choices for increasing power output in athletes. Management of fatigue in the weight room is one of the most important roles of a strength and conditioning coach training athletes. The role of fatigue in the performance of the squat and deadlift is well documented, however, there is a gap in the literature regarding the relationship between a dynamic movement like the clean and fatigue. Thusly, the purpose of this study is to determine the effects of fatigue on clean performance. We will be monitoring activation of the lower extremity muscles (knee flexors) during clean movements before and after a fatiguing protocol.

What you will do for this study
Consent Form and Questionnaires
You will be asked to complete the Physical Activity Readiness Questionnaire (PAR-Q). If you qualify for this study after these tests you will sign the consent form and complete all of the procedures listed below during the remainder of the testing session.

1) You will have your height and weight measured.

2) You will have the skin that covers the muscles of your thigh (vastus medialis, vastus lateralis,) cleaned with an alcohol pad on both legs.

3) You will then have four surface electromyography sensors placed on the cleaned areas.

4) You will warm-up on the isokinetic dynamometer where you will perform five isometric, concentric, and eccentric contractions with both your left and right legs.
5) After which, you will then perform three warm up clean lifts to work up to 50% of your one repetition maximum.

6) Following the warm-up, you will perform a total of six lifts (3 clean, 3 power clean), at 60%, 70% and 80% of your one repetition maximum. You will be provided a three-minute rest period between each lift.

7) You will then be seated on the isokinetic dynamometer to perform the fatigue protocol that consists of 30 maximal eccentric leg extensions with both legs.

8) Next you will then perform the above mentioned lifts at the same percentage of your one repetition maximum.

Time required for this study
This study requires 1 visit to the M. Joan Popp Motor Behavior Laboratory (213 Anderson Hall) lasting 1 hour and 15 minutes.

What Are The Risks of The Study?
Due to the nature of the study, you may experience muscular soreness due to the movements from exercise.

Are There Benefits to Taking Part in The Study?
There are no direct benefits to taking part in this study. However, you may experience satisfaction of learning and participating in a biomechanical research study.

What Are the Costs?
There is no cost to you for participating in this study.

Will I Be Paid For Participating in This Study?
There is no compensation for this research study.

Confidentiality
Efforts will be made to keep your personal information confidential. You will not be identifiable by name or description in any reports or publications about this study. Your personal information may be disclosed if required by law. There are organizations that may inspect and/or copy your research records for quality assurance and data analysis. These organizations include the Northern Illinois University Institutional Review Board (IRB), which is an organization that maintains the safety and integrity of research conducted here at the Northern Illinois University.

After removing all identifying information from your data, the information could be used for future research studies or distributed to another investigator for future research studies without additional informed consent from you.

What Are My Rights As a Participant?
Taking part in this study is voluntary. You may choose not to participate. Refusal to participate will involve no penalty or loss of benefits to which you are otherwise entitled. If you agree to participate and then decide against it, you can withdraw for any reason and leave the study at any time. However, please be sure to discuss leaving the study with the principal investigator.
Compensation for Illness or Injury
I understand that I am not waiving any legal rights or releasing the institution or their agents from liability from negligence. I understand that in the event of physical injury resulting from the research procedures, Northern Illinois University does not have funds budgeted for compensation for 1) lost wages, 2) medical treatment, or 3) reimbursement for such injuries. The University will help, however, obtain medical attention which I may require while involved in the study by securing transportation to the nearest medical facility.

IRB Approval
This study has been reviewed by Northern Illinois University’s Institutional Review Board (IRB). The IRB has determined that this study fulfills the human research subject protections obligations required by state and federal law and University policies. If you have any questions, concerns, or reports regarding your rights as a participant of research, please contact the IRB at 815-753-8588 or pwallace@niu.edu.

Please ask the researcher if there is anything that is not clear or if you need more information. When all your questions have been answered, then decide if you want to be in the study or not.

Statement of Consent
I have read the above information. I have been given a copy of this form. I have had an opportunity to ask questions, and I have received answers. I consent to participate in the study.

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Signature of Participant       Date

Printed name of Participant
APPENDIX B
PAR-Q

2021 PAR-Q+

The Physical Activity Readiness Questionnaire for Everyone

The health benefits of regular physical activity are clear; more people should engage in physical activity every day of the week. Participating in physical activity is very safe for MOST people. This questionnaire will tell you whether it is necessary for you to seek further advice from your doctor OR a qualified exercise professional before becoming more physically active.

GENERAL HEALTH QUESTIONS

Please read the 7 questions below carefully and answer each one honestly: check YES or NO.

1) Has your doctor ever said that you have a heart condition OR high blood pressure?

2) Do you feel pain in your chest at rest, during your daily activities of living, OR when you do physical activity?

3) Do you lose balance because of dizziness OR have you lost consciousness in the last 12 months?

4) Have you ever been diagnosed with another chronic medical condition (other than heart disease or high blood pressure)?

5) Are you currently taking prescribed medications for a chronic medical condition?

6) Do you currently have (or have had within the past 12 months) a bone, joint, or soft tissue (muscle, ligament, or tendon) problem that could be made worse by becoming more physically active? Please answer NO if you had a problem in the past, but it does not limit your current ability to be physically active.

7) Has your doctor ever said that you should only do medically supervised physical activity?

If you answered NO to all of the questions above, you are cleared for physical activity. Please sign the PARTICIPANT DECLARATION. You do not need to complete Pages 2 and 3.

Start becoming much more physically active – start slowly and build up gradually.

Follow Global Physical Activity Guidelines for your age (https://www.who.int/publications/i/item/9789240015128).

You may take part in a health and fitness appraisal.

If you are over the age of 45 yr and NOT accustomed to regular vigorous to maximal effort exercise, consult a qualified exercise professional before engaging in this intensity of exercise.

If you have any further questions, contact a qualified exercise professional.

PARTICIPANT DECLARATION

If you are under the legal age required for consent or require the assent of a care provider, your parent, guardian or care provider must also sign this form.

I, the undersigned, have read, understood and completed this questionnaire. I acknowledge that this physical activity clearance is valid for a maximum of 12 months from the date it is completed and becomes invalid if my condition changes. I also acknowledge that the community/fitness center may retain a copy of this form for its records. In these instances, it will maintain the confidentiality of the same, complying with applicable law.

NAME __________ DATE __________

SIGNATURE __________ WITNESS __________

SIGNATURE OF PARENT/GUARDIAN/CARE PROVIDER

If you answered YES to one or more of the questions above, COMPLETE PAGES 2 AND 3.

Delay becoming more active if:

- You have a temporary illness such as a cold or fever; it is best to wait until you feel better.
- You are pregnant – talk to your health care practitioner, your physician, a qualified exercise professional, and/or complete the eFitmed-XR at www.eFitmed-xr.com before becoming more physically active.
- Your health changes – answer the questions on Pages 2 and 3 of this document and/or talk to your doctor or a qualified exercise professional before continuing with any physical activity program.

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LIVEWORKSHEETS
APPENDIX C
ADDITIONAL FIGURES

Figure C1: Left vastus lateralis pre- and post-fatigue conditions across peak EMG activation relative to measured MVIC at given percentages of 1RM.

Figure C2: Left vastus medialis pre- and post-fatigue conditions across peak EMG activation relative to measured MVIC at given percentages of 1RM.
Figure C3: Right vastus lateralis pre- and post-fatigue conditions across peak EMG activation relative to measured MVIC at given percentages of 1RM.

Figure C4: Right vastus medialis pre- and post-fatigue conditions across mean EMG activation relative to measured MVIC at given percentages of 1RM.
Figure C5: Left vastus lateralis pre- and post-fatigue conditions across mean EMG activation relative to measured MVIC at given percentages of 1RM.