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A biomechanical comparison of successful and unsuccessful power clean attempts.

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Abstract
Although the power clean is an almost ubiquitous exercise in the strength and conditioning setting, relatively little is known about the biomechanics of successful and unsuccessful power clean lift attempts. The purpose of this study was to determine biomechanical differences between successful and unsuccessful power clean lift attempts in male collegiate athletes. Fifteen male lacrosse players (Age: 20.1 ± 1.2; Height: 1.78 ± 0.07 m; Body mass: 80.4 ± 8.1 kg; Relative one-repetition maximum power clean: 1.25 ± 0.13 kg/kg) were videotaped during a lifting session that required the completion of maximal effort power cleans to establish a one-repetition maximum. The position of the barbell was digitised and used to calculate the displacement, velocity, acceleration, and acceleration vector of the

barbell. The results revealed that unsuccessful attempts were characterised by differences during the second pull phase. Unsuccessful lifts exhibited greater peak forward barbell displacement, lower backward barbell velocities, and lower resultant acceleration angles during the second pull. Strength and conditioning coaches should therefore emphasise limited forward motion of the barbell during the second pull and instruct athletes to generate a more backward-directed force during the second pull in order to lift greater loads during testing and subsequent lifting sessions.

Keywords

Training/conditioning; weightlifting; biomechanics; kinematics; lacrosse

Introduction

There are a number of training modalities that are used to improve muscular power and strength as part of resistance training programmes (Arabatzi & Kellis, ; Arabatzi, Kellis, & De Villarreal; Hackett, Davies, Soomro, & Halaki; Hoffman, Cooper, Wendell, & Kang; Otto III, Coburn, Brown, & Spiering,; Tricoli, Lamas, Carnevale, & Ugrinowitsch). These programmes often incorporate weightlifting exercises, or derivatives of these exercises, because of biomechanical similarities and high degree of specificity in relation to other athletic movements that require an explosive triple extension of the lower extremity joints (Chiu & Schilling,). In addition, cross-sectional studies indicate that better performance in weightlifting movements is correlated to better sprinting and jumping performance (Carlock et al.; Hori et al.,). Moreover, longitudinal studies show that the use of weightlifting exercises leads to greater and broader improvements in dynamic performance than the use of more traditional resistance training exercises (Hoffman et al.; Otto III et al.; Tricoli et al.).

One of the most frequently used variations of a weightlifting exercise in the strength and conditioning setting is the power clean (Chiu & Schilling; Garhammer). The majority of studies that have examined the power clean have focused on the differences between loads that produce the greatest forces, rates of force development, and power outputs so as to better guide training efforts aimed at improving these specific biomechanical variables (Comfort, Fletcher, & McMahon; Cormie, Mccaulley, Triplett, & Mcbride). Since these biomechanical variables are mostly optimised during sub-maximal efforts, few studies have focused on the biomechanics of near-maximal (i.e. ≥90%) effort power cleans (Winchester, Erickson, Blaak, & McBride), and even less is known about the biomechanics of power clean attempts where the weight is too heavy to successfully complete the lift. However, knowledge about the biomechanics of maximal effort power cleans and the biomechanical differences between successful and unsuccessful power clean attempts would inform coaching practices and facilitate training efforts in that athletes could lift greater loads during testing sessions and also during subsequent training sessions.

Given that the power clean is a frequently used and studied exercise, it is surprising that no studies have examined the biomechanical differences between successful and unsuccessful power clean attempts. The only comparable data on successful and unsuccessful lift attempts for weightlifting exercises exist for the snatch (Gourgoulis, Aggelousis, Garas, & Mavromatis; Hoover, Carlson, Christensen, & Zebas; Stone, O'Bryant, Williams, & Johnson). Stone et al.) investigated differences in barbell kinematics between successful and unsuccessful snatch attempts and found that during successful attempts, international weightlifters move the barbell with greater vertical forces, begin the second pull from a slightly more backward position, and catch the barbell in a less backward overhead position (Stone et al.). Gourgoulis et al.) also studied biomechanical differences between successful and unsuccessful snatch attempts and reported that the only kinematic variable that differed between successful and unsuccessful snatch lifts of elite weightlifters was the angle of the resultant acceleration vector during the first pull of the snatch.

Based on the aforementioned research findings, it appears that the biomechanics of unsuccessful snatch lifts performed by elite weightlifters are characterised by aberrant biomechanics during the first and second pull (Gourgoulis et al.; Stone et al.). Aside from biomechanical similarities in the pull phase, the power clean, however, is a different lift and is most often performed by non-weightlifters in the strength and conditioning setting. Identifying the biomechanical differences between successful and unsuccessful power clean attempts would aid coaches and facilitate the training of athletes in that they would be able to lift maximal loads more effectively during testing sessions, and would also allow them to lift heavier weights during subsequent training sessions where the intensity is based on weights lifted during testing. The purpose of this study was therefore to compare the biomechanics of successful and unsuccessful maximal power clean attempts. We hypothesised that the successful and unsuccessful power clean attempts would exhibit biomechanical differences in barbell kinematics and kinetics during the first and second pull phases.

Methods

Participants

Fifteen male participants (Mean ± SD; Age: 20.1 ± 1.2 ; Height: 1.78 ± 0.07 m; Body mass: 80.4 ± 8.1 kg; One-Repetition Maximum (RM) power clean: 100.4 ± 8.1 kg; Relative One-RM power clean: 1.25 ± 0.13 kg/kg) agreed to have their lift sessions videotaped as part of this study. All participants were part of an National Collegiate Athletic Association Division I Men's lacrosse team, which won its conference championship and was ranked among the top 15 of all collegiate teams in the USA during the 2016 season. All athletes were actively engaged in resistance training programmes that involved weightlifting exercises, such as the power clean. The testing occurred after a 12-week strength and power training phase and took place during a testing week of their pre-season training phase. All participants provided informed consent. The study was approved by the Marquette University Institutional Review Board for Human Subjects Testing.

Procedures

All athletes were able to go through their usual dynamic warm-up routine, which included brief aerobic activity (jumping rope) and brief sets of body weight exercises (e.g. lunges, squats), and followed a standard protocol for one-RM testing. Briefly, the testing protocol involved the completion of several sub-maximal sets of the power clean, the repetition ranges for these sets were between two and three reps. Once an athlete reached 80% of his previous one-RM he would proceed to only completing single repetitions at each weight. The weight was then progressively increased by increments of 2.5–5% until a new one-RM was established. The rest periods between sets were freely chosen by the athletes, but generally fell within a 2–3 minute time frame. A successful power clean was defined as the athlete catching the barbell on the front of the shoulders in a squat position with the knee bend not exceeding 90°. These criteria were confirmed through visual inspection of the recorded video data.

In order to record video data during the lifting session, a digital video camera (Basler ACE a2000 GigE, Basler AG, Germany) was set up on a tripod perpendicular to the lifting platform at an approximate distance of 3 m so as to capture the sagittal plane motion of the lifters and barbell. The camera was positioned such that the centre of the video capture screen coincided with the centre of the platform in the horizontal direction and with the approximate centre of mass of the athletes in full view in the vertical direction. Video for all lift attempts was recorded on a laptop with TEMPLO software (Contemplas GmbH, Germany) at a sampling frequency of 60 Hz. Each data recording was saved for later offline analysis.

The processing of the video data began with tracking the position of the end of the barbell. An automated tracking algorithm was used (TEMPLO, Contemplas GmbH, Germany) for digitisation. The tracked *x*–*y* coordinates were converted into metric units through a scaling procedure (TEMPLO, Contemplas GmbH, Germany) that used the diameter of a standard 20-kg plate (Eleiko Sport USA, USA) as a known quantity (Garhammer). The tracked *x*–*y* coordinates were then exported into spreadsheets (Excel, Microsoft, USA). The exported *x*–*y* coordinate data were smoothed with a low-pass Butterworth filter at 6 Hz. The filtered barbell position data were differentiated with the central difference method in order to calculate barbell velocities (Winter). In turn, the barbell velocities were differentiated again in order to calculate barbell accelerations (Winter).

Variables of interest related to barbell position data were extracted and calculated from the filtered kinematic data. Specifically, the horizontal movement of the barbell was described by two bar path positions (i.e. displacements) similar to Stone et al.): start position to beginning of second pull (1st Pull Backward) and start position to end of second pull (2nd Pull Forward). The vertical movement was described by the vertical displacement of the barbell between the start position and the maximum height (Vertical). In addition, the velocity and acceleration data of the barbell in the vertical and horizontal directions, as well as the average resultant angle of the acceleration vector during various pull phases were extracted and analysed (Gourgoulis et al.; Isaka, Okada, & Funato). Specific velocity data included the vertical and backward velocities during the first pull, and the vertical and backward velocities during the second pull. The vertical velocities and accelerations during the transition were not analysed because some velocity profiles did not exhibit distinct decreases during this phase. Specific acceleration data included the vertical and backward accelerations during the first pull, and the vertical and backward accelerations during the second pull. Lastly, the average resultant angles of the acceleration vector during the first and second pull were also calculated with respect to the horizontal axis (i.e. 90° = direct upward movement). The time series data of each participant were linearly interpolated to 101 data points that represent the time from when the barbell broke contact with the ground and the maximum height of the barbell. These time-normalised data were then used to create ensemble average time-series graphs of the dependent variables of successful and unsuccessful power clean attempts.

Statistical analyses

The independent variable of this study was lift success (i.e. successful and unsuccessful). The dependent variables of this study were the displacements, velocities, and accelerations of the barbell during the different phases of the power clean. In order to compare all dependent variables between successful and unsuccessful maximal power clean attempts, paired *t*-tests were used. Levene's test was used to check the equality of means assumptions associated with the chosen test statistic. The standard of proof to show statistical significance for all analyses was set at a level of $\alpha = 0.05$. The alpha level was not adjusted for multiple comparisons for two reasons. First, given the lack of research into the comparison between successful and unsuccessful power clean attempts this study was considered exploratory, and second we prioritised limiting the chance of false negatives over committing type II errors (Perneger). In addition, effect sizes (Cohen's *d*) were calculated to help with the applied interpretation of all *p*-values. The magnitude of the effect sizes were interpreted as small (~0.2), medium (~0.5), and large (~0.8) (Cohen). All statistical analyses were performed using SPSS version 21.0 (IBM Corp, USA).

Results

The statistical analyses indicated several statistically significant differences with large effect sizes between peak data of successful and unsuccessful maximal power clean attempts (Table 1). Unsuccessful lifts were characterised by greater peak forward barbell displacements (Figure 1), lower backward barbell velocities (Figure 2), and lower resultant acceleration angles during the second pull (Figure 3).

Table 1. Mean ± SD peak barbell displacement (cm), velocity (m/s), acceleration (m/s2), and average resultant angle (°) data during the first and second pull of successful and unsuccessful power clean attempts.

	Power clean attempt			
	Successful	Unsuccessful	p-value	Effect size
Displacement data				
1st pull backward	−6 ± 4	−4 ± 1	0.426	0.54
2nd pull forward	7 ± 5	15 ± 2	0.023	1.87
Vertical	101 ± 5	97 ± 9	0.133	0.56
Velocity data				
1st pull backward	−0.24 ± 0.09	−0.16 ± 0.05	0.057	1.07
1st pull vertical	1.42 ± 0.22	1.35 ± 0.21	0.587	0.29
2nd pull backward	−0.48 ± 0.14	−0.29 ± 0.19	0.032	1.23
2nd pull vertical	1.66 ± 0.12	1.60 ± 0.11	0.375	0.47
Acceleration data				
1st pull backward	−1.36 ± 0.50	−1.10 ± 0.33	0.269	0.60
1st pull vertical	4.79 ± 1.44	5.40 ± 1.11	0.587	0.46
1st pull resultant angle	−2 ± 14	7 ± 23	0.365	0.48
2nd pull backward	−5.90 ± 1.35	−5.94 ± 1.48	0.965	0.02
2nd pull vertical	4.21 ± 1.09	4.51 ± 2.02	0.375	0.20
2nd pull resultant angle	135 ± 18	112 ± 21	0.032	1.23

1 Note: All significant *p*-values ($p < 0.05$) are denoted in italics.

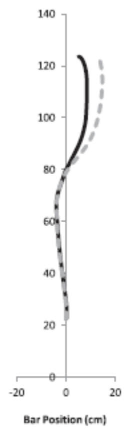

Figure 1. Ensemble average barbell positions (cm) of successful (black) and unsuccessful (dashed-grey) power clean lift attempts.

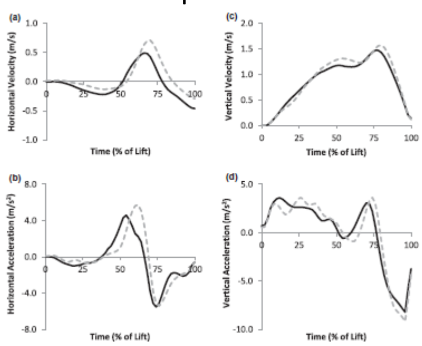

Figure 2. Ensemble average (a) horizontal and (b) vertical velocities (m/s) of successful (black) and unsuccessful (dashed-grey) power clean lift attempts. Ensemble average (c) horizontal and (d) vertical accelerations (m/s2) of successful (black) and unsuccessful (dashed-grey) power clean lift attempts.

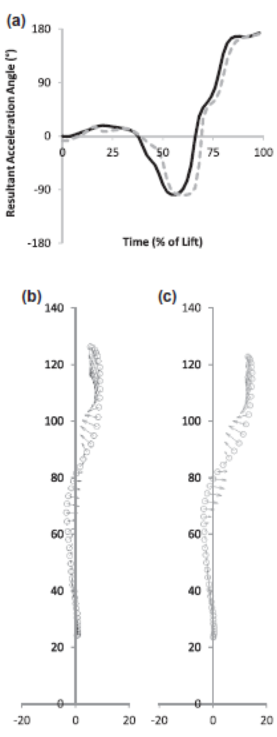

Figure 3. Ensemble average (a) resultant acceleration angles (°) of successful (black) and unsuccessful (dashed-grey) power clean lift attempts. Ensemble average barbell positions (cm) of (b) successful and (c) unsuccessful power clean lift attempts with resultant acceleration vectors superimposed at each time point.

Discussion and implications

The purpose of this study was to compare the biomechanics of successful and unsuccessful maximal power clean attempts. We hypothesised that the successful and unsuccessful power clean attempts would exhibit biomechanical differences in barbell kinematics and kinetics throughout the various pull phases. The results, however, only partially supported this hypothesis and indicated that unsuccessful power clean attempts were characterised primarily by differences during the second pull phase. Specifically, unsuccessful lifts exhibited greater peak forward barbell displacements, smaller backward barbell velocities, and smaller resultant acceleration angles during the second pull. Collectively these results indicate that unsuccessful power clean attempts were characterised by aberrant force application during the second pull, which has important implications in regard to helping athletes successfully lift greater loads during testing and lifting sessions.

One of the primary findings of this study indicated that the peak forward displacement of the barbell during the second pull was greater for unsuccessful than successful maximal power clean attempts (see Figure 1). Although no comparative kinematic data on successful and unsuccessful data exist for the power clean, Stone et al. presented barbell position data on successful and unsuccessful data for the snatch. Based on their results, these authors suggest that excessive forward displacement between the start of the second pull and the point where the barbell begins to move vertically towards the end of the second pull is a contributor to failed snatch attempts. The same authors hypothesised that such excessive forward motion occurs due to 'hipping the bar' forward and away from the lifter, which may result from shifting the centre-of-pressure underneath the feet forward and coming up on the toes too early. Indeed, this hypothesis is supported by force plate data from Garhammer and Taylor, who showed that anterior–posterior motions of the centre-of-pressure underneath the feet of weightlifters are closely linked to barbell motions during the execution of weightlifting exercises. Interestingly, these authors showed that the forward motion of the centre-of-pressure temporally precedes the forward motion of the barbell, which would suggest that aberrant body motions (e.g. 'hipping the bar' and rising onto the toes too early are directly responsible for excessive forward barbell displacements, as observed in the current study. Furthermore, Stone and colleagues suggested that such aberrant body motions are associated with a misdirection of the force that is applied to the barbell, which may lead to a lift attempt being unsuccessful.

In the current study, we investigated the direction of force application onto the barbell by calculating the angle of the resultant acceleration vector during the various pull phases. Specifically, we found that the resultant angle of the acceleration vector of successful power clean attempts was directed more backward and towards the lifter during the second pull phase, which would indicate an application of net force in the same direction. Stone et al. hypothesised that faulty barbell motions during the second pull, such as those described in the preceding paragraph, are often the result of inappropriately applied vertical forces. This hypothesis is thus supported by our data, and is reinforced by visual inspection of Figure 3, which depicts the interaction between barbell displacement and the acceleration vector during the successful and unsuccessful power clean attempts. Other authors have also reported that the proper application of the resultant force and direction of the barbell acceleration vector is crucial for successful performance in the snatch (Gourgoulis et al. Specifically, Gourgoulis et al. reported that the resultant angle of the acceleration vector during the first pull of the snatch was the only barbell kinematic variable that differed between successful and unsuccessful snatch lifts. Interestingly, these authors also noted that the general movement patterns and positions of the limbs did not differ between successful and unsuccessful lifts, which would suggest that the differences in force application and acceleration direction are more likely driven by the internal joint kinetics and not the joint kinematics. Future studies should therefore consider investigating these variables in relation to the success of maximal weightlifting attempts. It remains unclear why the resultant angle of the acceleration vector of successful and unsuccessful snatch lifts differed during the first pull in the study by Gourgoulis and colleagues but during the second pull in the current study. Perhaps this difference is simply due to the nature of the difference between the lifts that were studied (i.e. snatch vs. power clean).

In addition, results from the current study indicated that the peak backward velocities during the second pull were smaller for unsuccessful power clean attempts. Given that the peak horizontal accelerations did not differ between successful and unsuccessful power clean attempts, the difference in backward barbell velocity during the second pull is likely due to the observed difference in the direction in which the lifters applied force and the resulting angle of the barbell acceleration vector (Isaka et al.). Further, it is interesting to note that while the vertical accelerations did not differ between successful and unsuccessful power clean attempts in the current study, visual inspection of the time series data indicates a temporal delay in the time of peak vertical barbell acceleration during the second pull of unsuccessful power clean attempts. It may be conceivable that the spatiotemporal structure of either barbell or joint kinematic and kinetic data provides better insights since discrete peak angles and body positions do not appear to discriminate between successful and unsuccessful snatch lifts (Gourgoulis et al.). Indeed, delays in hip and knee extension angles during the second pull appear to be characteristics of lesser skilled weightlifters, and are thought to limit these joints' contribution to effectively applying force to the barbell (Ikeda et al.) and maximising weightlifting performance (Kipp, Redden, Sabick, & Harris). Given a well-established weightlifting technique, the well-known force–velocity constraints of human movement may affect its temporal structure (i.e. timing) to a greater extent than its magnitude (i.e. peak joint angle) during heavier maximal lift attempts. However, given that this study did not explicitly investigate differences in joint kinematics, kinetics, and timing between successful and unsuccessful power clean attempts, the conclusions about spatiotemporal differences between successful and unsuccessful power clean attempts should be interpreted with caution.

Conclusion

The power clean is one of the most frequently used variations of weightlifting exercises and is often used to improve muscular power and strength as part of resistance training programmes in a strength and conditioning setting. Being able to lift maximal loads more effectively during testing sessions may allow athletes to lift heavier weights during subsequent training sessions where the intensity is based on lift weights achieved during testing. The biomechanical differences identified between successful and unsuccessful power clean attempts in the current study could therefore be used to facilitate the training of athletes. Unsuccessful maximal effort power clean attempts were characterised primarily by biomechanical differences during the second pull phase. Unsuccessful one-RM power clean attempts exhibited greater peak forward barbell displacements, smaller backward barbell velocities, and smaller resultant acceleration angles during the second pull. These results highlight that unsuccessful power clean attempts are characterised by aberrant force application during the second pull. Strength and conditioning professionals should therefore emphasise limited forward motion of the barbell during the second pull and instruct athletes to do so through a more backward directed application of force onto the barbell during the second pull.

Disclosure statement

The authors declare no potential conflict of interest.

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