OLYMPIC WEIGHTLIFTING: QUANTIFYING THE DYNAMICS OF THE CLEAN

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ABSTRACT

Olympic-style weightlifting is an extremely quick and explosive sport, with a high correlation between force exertion on the barbell and the acceleration of the barbell. Determinants of a successful lift are how high a weightlifter can propel the bar and also how fast a weightlifter is able to descend to receive the barbell at the full squat position. The position where the bar is propelled upwards with the greatest force occurs at the 2nd pull phase, when torque forces on the back are minimized. This study measured the peak force generated by a weightlifter during the clean movement, as well as the accelerations of the barbell and torso. With this data, the power generated during the clean was also determined. Overall, the measured peak force was 1940 ± 220N, the measured peak acceleration of the barbell was 21.8 ± 3.7 m/s^2 and that of the torso was 40 ± 19 m/s^2. The power generated by the 1st pull was 1170 ± 430 W while the power generated by the 2nd pull was 3100 ± 350 W. The results demonstrate the immense power generated by the 2nd pull during the clean, suggesting an effective way to train for explosive strength. Most importantly, this study determines the significance of weightlifting data and its implications for performance.

INTRODUCTION

Olympic-style weightlifting comprises of two lifts, the snatch and the clean and jerk, both with the goal of propelling the bar to the overhead lockout position. The snatch is performed with one swift motion, from lifting the barbell off the ground directly overhead in lockout position. The clean and jerk is performed by lifting the barbell to the shoulders and then propelling the barbell to the overhead position. Both lifts are executed extremely quickly, usually around 1 second in duration and test the limits of human ballistic strength. Olympic–style weightlifting generates some of the highest forces and power in all of sports. This study is primarily concerned with the kinematics related to the clean portion of the clean and jerk movement. The kinematics of the shoulder to overhead lockout movement of the jerk will not be discussed.

Because Olympic lifts are performed so quickly, it is often difficult for athletes to accurately judge kinematics by themselves and adjust accordingly. Barbell acceleration, velocity, and height to which the barbell travels all play a significant part in determining a successful lift. Knowing optimal acceleration and the force necessary to achieve that acceleration can help weightlifters understand if they pulled too hard or not hard enough. In addition, further calculations like peak power generated by the lifter can also be estimated through these measurements. This study sought to quantify the dynamic forces present during the clean via sensors and video analysis. Such data is important because weightlifting analysis technology can be developed to provide real time feedback to athletes during training. For example, a device can monitor body motion, force, acceleration, bar path and height and give recommendations on how to improve form or technique. Ultimately, taking real-time data during weightlifting can help with the planning of training and monitoring of a weightlifter's progress in strength over time.

In order to perform the measurements of the clean movement, the clean was performed by 1 subject while standing on two force plates with one foot on each plate. A low-G accelerometer was attached to the neck area just above shoulder level and a 3-axis accelerometer was attached to the side of the barbell. The following sections will discuss the basic principles behind the Olympic Clean, discuss the results and also expand upon exciting possibilities of using weightlifting data.

KINEMATICS AND BIOMECHANICS OF THE CLEAN

The kinematics of an Olympic-style lift such as the clean is very complex and varies from lifter to lifter. The variations in technique among lifters result in different "bar paths," the imaginary path the bar takes as it travels upwards. Ideally, the straighter the path going up, the more efficient forces exerted on it are since there is less force wasted toward lateral barbell movement [4]. The motion recruits a majority of the muscles in the body, with the gluteus, back muscles, and quadriceps as the major sources of power during the lift. When the bar is first pulled up off the floor, the motion resembles that of a deadlift, known as the first pull (Figure 1). The purpose of the first pull is ultimately to bring the barbell to the "power position" at the 2nd pull, which is when the back is near vertical and the barbell is around mid thigh height with the knees bent. The arms are straight and the back is tight at around a 45-degree angle while the hips and knees extend. When the bar reaches the knee, the back begins to straighten into a more upright position around 90 degrees while the knees and hips are still bent. When the bar reaches around mid thigh, the weightlifter undergoes a very quick triple extension of the hips, knees and then ankles (the 2nd pull). The force exerted upon the barbell at the triple extension point is concentrated toward the toes of the foot. The violent shrugging of the upper back pulls the lifter into a deep front squat position.

The second pull is the most critical part of the clean that determines whether the barbell can be pulled to the optimal height for the weightlifter to catch in the squat position. In addition, the acceleration of the barbell is directly proportional to the force exerted upon the bar by the weightlifter since the mass is constant. Therefore, as the weightlifter exerts more force to accelerate the barbell upward, the velocity increases. However, faster does not necessarily mean better, since there needs to be a careful balance of barbell height, just enough so the weightlifter can get underneath and does not waste energy or lose control.

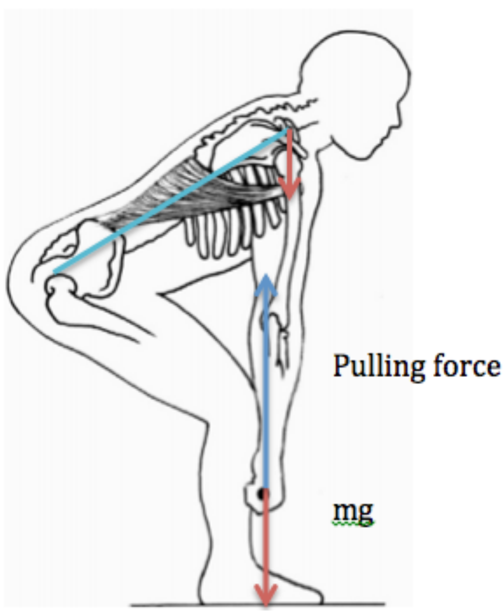

Figure 1: During the start of the lift, the weightlifter has to counter the forces exerted by the barbell on the hands by tightening the posterior chain. The hips act as a pivot as the back and legs exert counteracting forces to keep the back upright against the torque forces.

The arms, torso and legs need to be aligned vertically in order for the weightlifter to exert the most vertical force. The weightlifter reaches the 2nd pull position just as the barbell passes the knees, from which the weightlifter can exert maximum force since there are no more torque forces exerted on the back, and only compressive forces due to the weight (Figure 2). This is the so-called “power position.”

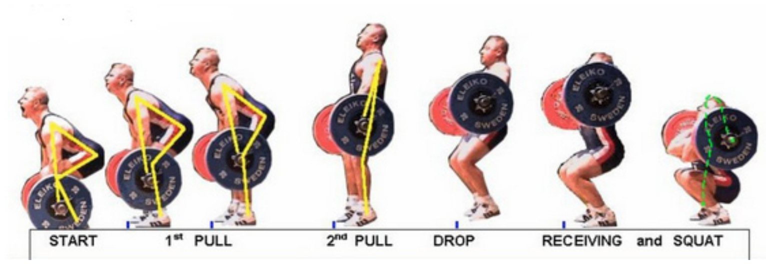

Figure 2: Sequence of the clean, demonstrating the start, 1st pull, 2nd pull and receiving of the barbell. The alignment of arms, torso and legs are shown as forces are converted from torque forces to compressive forces. The weightlifter closes the yellow triangular gap formed by the arms, back and thighs as he reaches the 2nd pull phase. [2]

There are several important equations governing the physics of weightlifting, the first governing force, Newton’s 2nd Law (equation {1}) where *m* represents the mass of the barbell and *a* represents the acceleration of the barbell. The maximum force can be calculated using the maximum measured acceleration at the peak of the 2nd pull. However, the calculated force is not representative of the entire force generated by the weightlifter & barbell system. In addition to accelerating the barbell, the weightlifter accelerates his own bodyweight during the clean as well, resulting in a higher measured force plate reaction force than that calculated by {1}.

$$Force = m * a \qquad \{1\}$$

The second important equation calculates power generation during the clean {2}. Due to the changing lever points and non-constant acceleration, work could not be reasonably estimated with $W=m*g*d$. Therefore the power generated during the lift could not be accurately calculated by $P=W/t$. However, through video analysis of barbell path and height, the velocities of both the 1st pull and 2nd pull were determined. By multiplying the average force during the 1st pull by the average velocity of the 1st pull, power during the 1st pull was determined. Likewise, the power of the 2nd pull was calculated by multiplying force by the average velocity of the 2nd pull. *F* represents force, whereas *v* represents average velocity.

$$P = F * v \qquad \{2\}$$

The data collected from force plate and accelerometer measurements demonstrate the correlations between Force and Acceleration during the lift. The data also shows the different phases of the clean and provides very clear markers of when certain parts of the lift are taking place (figure 3).

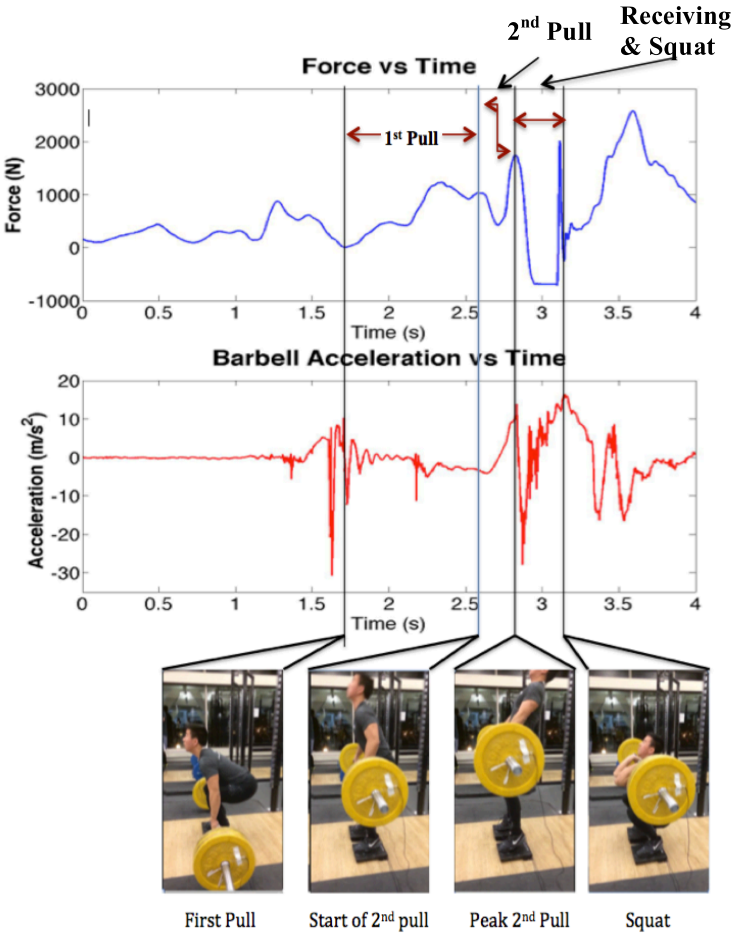

Figure 3: Raw sensor data taken by force plates and accelerometer. The two graphs are calibrated with respect to time, and significant time markings are correlated with sequence pictures at the bottom. The vertical lines represent the time marking where each sequence visual takes place. The area between the vertical lines are divided into the 1st pull, 2nd pull, and receiving phase, respectively. The graphs demonstrate a close correlation between force plate reaction force and acceleration of the barbell during the lift.

MEASUREMENT OF ACCELERATION AND FORCE

This experiment measured the acceleration of the barbell, acceleration of the torso as well as the ground reaction force. The setup of the experiment involved a low-g accelerometer, a 3-axis accelerometer and two force plates (figure 4). The barbell was loaded with a total mass of 80kg and a total of six cleans were performed by the single test subject. To make the most accurate measurements of force and acceleration, the measurement setup was zeroed with the test subject standing on the force plate, in the position shown in figure 4, but without any force exerted on the barbell. This allowed a more accurate measurement of the force exerted on the 80kg barbell without the added force of bodyweight. The 3-axis accelerometer was oriented so that +Y was pointing downwards, and the LGA accelerometer was oriented so that acceleration was positive pointing upwards. All the sensors were set to sample at a rate of 500 Hz.

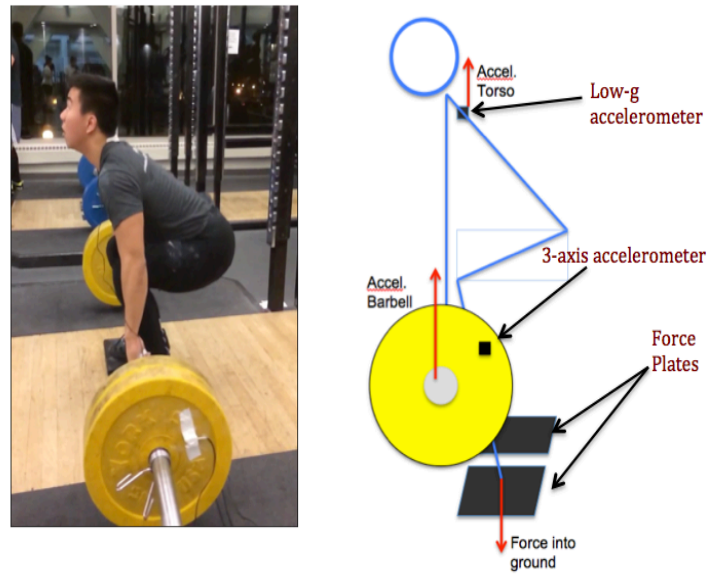

Figure 4: Setup of the weightlifting experiment demonstrating the locations of the various sensors. The low-g accelerometer on the neck measures the acceleration of the torso; the 3-axis accelerometer measures acceleration of the barbell and the force plates measure the ground reaction force.

The film of the sixth lift was used to create the sequence montage (figure 5). The clean was recorded using an iPhone 5s slow motion camera at a rate of 120 frames per second. The playback rate on the computer was 1/4th the normal speed. The whole lift takes place over 5 seconds in playback time, corresponding to 1.25 seconds real time from the weight first coming off the ground to the bottom squat position (frames 1-14).

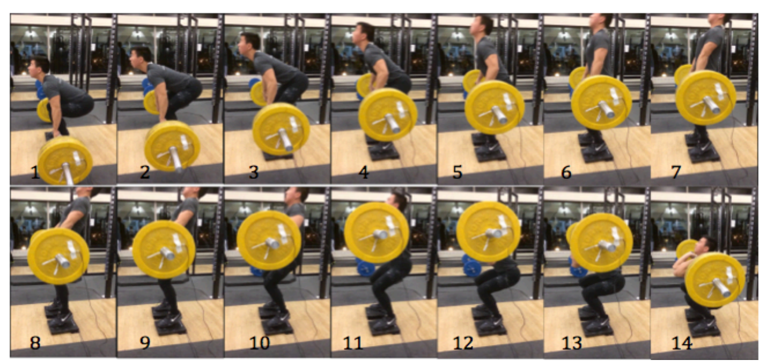

Figure 5: Sequence of clean; straight bar path, straight extension into the ground. #1-4 shows the 1st pull, #5-8 shows the power position and the 2nd pull phase and #9-14 shows the receiving phase that are highlighted by the graphic of figure 2. The frames taken from the slow motion recording were very useful for data analysis since the height of the barbell path could be tracked, therefore providing distance and velocity data.

RESULTS AND DISCUSSION

During the experiment, only one force plate was working, so the total force generated during the lift was determined by multiplying the measurement obtained from one leg by two. Overall, the measured peak force was 1940 ± 220N, the measured acceleration of the barbell was 21.8 ± 3.7 m/s^2 and that of the torso was 40 ± 19 m/s^2 (figure 6). During the first pull, the distance the barbell traveled was 0.6m in a time of 0.5s to the height just past the subject's knees. During the second pull, the distance traveled from the knees to the maximum barbell height was 0.48m in a time of 0.3s. Therefore, the average velocity of the barbell during the 1st pull was 1.2 m/s and that of the 2nd pull was 1.6 m/s. The distance traveled by the torso during the receiving phase was measured to be 0.71m, with duration of travel of 0.4s. The average velocity of the torso during descent was 1.77 m/s.

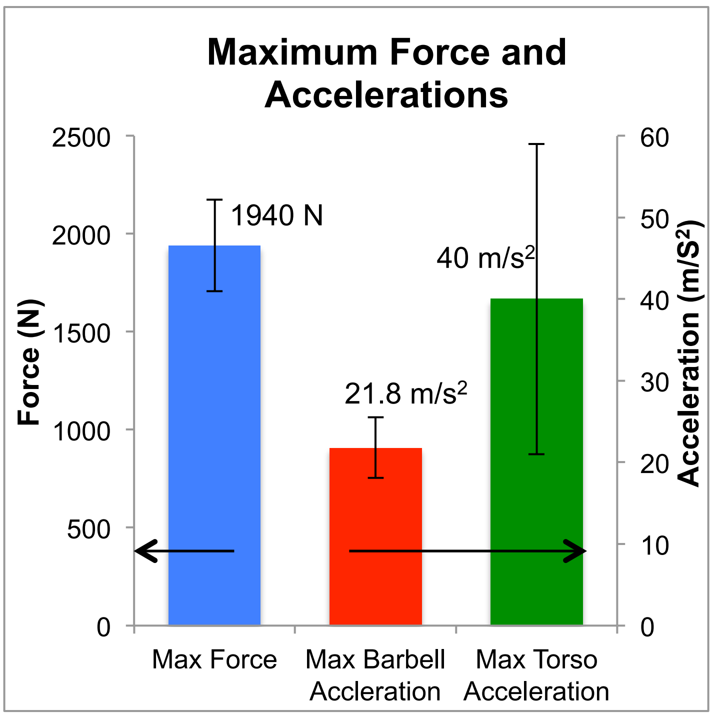

Figure 6: The bar graphs demonstrate the peak measurements that were obtained in this experiment as well as their corresponding precision errors in the form of error bars.

Force calculated with equation {1} using barbell acceleration results in a force of 1740N. The estimated peak force falls within the precision range of 1940 ± 220N. However, the measured force from the force plates is ultimately higher due to the additional force necessary to accelerate body weight.

The test subject's maximum clean is 130kg so the 80kg used in the trials represents around 61% of his 1 rep maximum (1RM). In addition, the subject's bodyweight was also 80kg. In the study of barbell acceleration in relation to weightlifting intensity done by Sato [1], the mean peak barbell acceleration measured at the 2nd pull was 19.63 ± 3.04 m/s^2 at 80% of 1 rep max. Therefore, the result obtained in this experiment of 21.8 ± 3.7 m/s^2 done at a lower percentage of 1RM reflects the trend of decreasing barbell acceleration as mass increases. Perhaps the weight chosen for this experiment was slightly low, since the subject is able to clean 80kg directly to the shoulders without having to full squat all the way down. The balance between barbell weight and bodyweight affects acceleration and the dynamics of the clean. If the subject had performed cleans without having to receive the bar at the bottom, the acceleration of the bar should be higher. However for the sake of safety and accuracy while standing on the force plates, the weight was chosen as such. Nevertheless, comparing the experimental acceleration to literature demonstrates a trend of decreasing barbell acceleration with increasing weight.

The peak power generated during the 1st pull was 1170 ± 430 W and that of the second pull was determined to be 3100 ± 350W, with a total power of 4270W ± 780W (Figure 7). The results demonstrate that the power of the 2nd pull is almost 3 times a large as the 1st pull. The large difference in data is perhaps due to the biomechanical advantage of the 2nd pull. The weightlifter is allowed to extend vertically to maximum contraction during the 2nd pull, whereas torque forces on the back limit the weightlifter during the 1st pull. A similar study done by Comfort [3] validates the power generation during the 2nd pull, as the power generated by his test subjects was found to be 2591.2 ± 645.5W using a 60% 1RM weight.

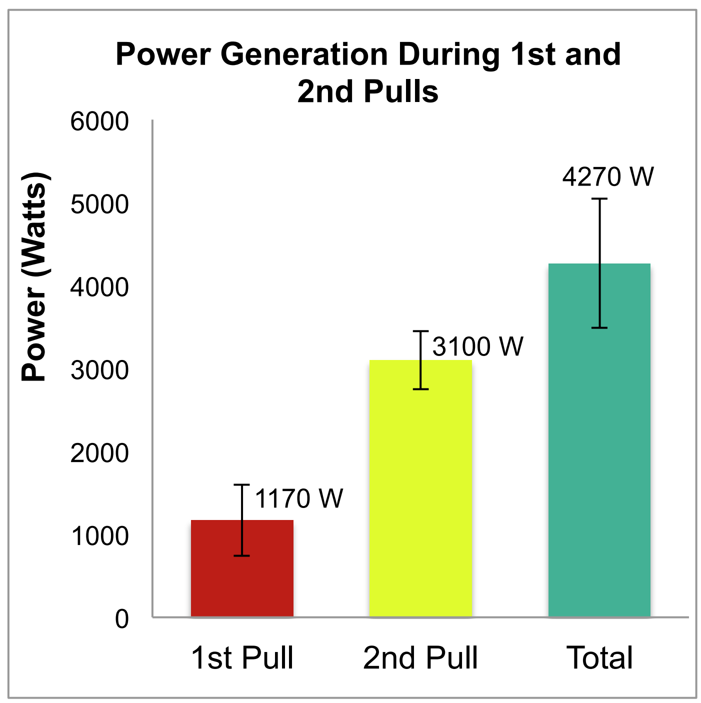

Figure 7: Power comparison between the 1st pull and 2nd pull. The total power of the clean was also calculated. The power calculations were derived through force measurement for both pull phases and the average velocities of the barbell during each phase.

CONCLUSION

Overall, the goal of this experiment was to quantify the various forces and motion dynamics of the clean movement using an 80kg barbell. The results were then compared to those of previous weightlifting literature and were demonstrated to have high correlation with the other research results regarding power and acceleration. Using the force and barbell velocity, the power output during the 2^{nd} pull was calculated to be 3100 ± 350W. The peak force was measured to be 1940N ± 220N. The measured peak acceleration of the barbell was 21.8 ± 3.7 m/s^2 and that of the torso was 40 ± 19 m/s^2. The results and previous weightlifting literature demonstrate the trend that as barbell weight increases, barbell acceleration decreases as well as its velocity. However, an increase in barbell weight causes torso acceleration to increase in order to receive the barbell quicker. This phenomenon results from the ratio between weightlifter mass and barbell mass, which affects dynamics of the clean as the ratio changes.

The results of this study demonstrate that the contractile force generated by the posterior chain and legs during explosive movements are extremely quick and powerful, taking place in the timeframe of fractions of a second. The 2^{nd} pull of the clean generates considerably more power and force than the 1^{st} pull phase and is also shorter in duration. Thus, the results suggest that athletic training for explosive power should be aimed towards maximizing the force generated at the "power position" of the 2^{nd} pull. Sports such as track sprinting, basketball, and high jumping all utilize this "power position" motion with triple extension of the hips, knees and ankles. Athletes can therefore simulate this motion by simply performing the clean from the mid thigh, without having to start all the way from the ground.

Further investigation into weightlifting and explosive power can look at comparisons of force exertion and accelerations of the barbell at different percentages of 1-rep maxes by using different barbell masses. Using different barbell masses can compare force generation, acceleration, barbell height and torso speed as the weight resistance increases. This study can correlate the relationship between the weightlifter mass to barbell mass ratio and other dynamic parameters. In addition, investigating the effect of different starting positions, such as starting from the ground versus starting directly at the power position can also be valuable ways to compare power, force and acceleration.

This study demonstrated the valuable implications of obtaining quantitative data during the clean. Ultimately, a significant amount of information was acquired simply through video analysis, accelerometer and force plate measurements. Ideally, a weightlifting monitoring system can be developed that tracks the motions of the weightlifter as well as the dynamic data during the lift, such as barbell height, barbell velocity, weightlifter velocity and force. After investigating the relationships between the weightlifter and barbell mass ratio with respect to forces and accelerations, the system can be calibrated so that it will give feedback to weightlifters. A smart weightlifting system will be able to give weightlifters suggestions on how to improve their lifts, such as telling them if they lifted too high or too low, used inefficient technique, or lifted the barbell at the wrong speed, among many other parameters. Therefore, using such measurements like those performed in this study is useful to weightlifters and other athletes seeking to improve their explosive power ability.

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