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Ground Reaction Forces During the Power Clean

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ABSTRACT

Identifying and understanding the key biomechanical factors that exemplify the power clean can provide athletes the proper tools needed to prevail at a competitive event. Therefore, the purpose of this study was to characterize and describe ground reaction forces (Fz) during the power clean lift. Three 60-Hz motion-detecting cameras and an AMTI force plate were used to collect data from 10 collegiate weightlifting men who performed a power clean at 60 and 70% of their last competitive maximum clean. The results revealed that a greater peak force (Fz) was produced during the second pull compared with the first pull and unweighted phases in both percentage lifts. As the system weight increased from 60 to 70%, the peak force (Fz) increased for the first pull and unweighted phases and decreased during the second pull phase. Learning the proper technique of the power clean may provide athletes the basic understanding needed to be competitive in a weightlifting or sporting event.

Key Words: biomechanics, force measurement, Olympic lifts

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Introduction

When training an athlete for competition, the exercises implemented in his or her workout should duplicate the movements performed in the sport itself. Many strength coaches believe this theory and train their athletes with Olympic-style lifts (2, 9, 10). The Olympic lifts require speed, precision, explosive power, and year-around training to become proficient in this sport (7, 16, 17, 19). Strength coaches believe that athletes need to focus on attaining a sound technical base when performing any Olympic-style lifts (1, 5, 13).

Enoka (3) examined 5 experienced weightlifters' techniques during the pull portion of a clean. The author found that the clean pull was divided into 3 phases: first pull, unweighted, and second pull. The subjects created a peak ground reaction force (Fz) of 2,471 N during the first pull phase (3). During the unweighted phase, the ground reaction force decreased to 1,425 N, whereas the second pull phase created a maximal peak ground reaction force with an average of 2,809 N. The author concluded that the second pull phase required the greatest peak ground reaction force, followed by the first pull and unweighted phases. Hakkinen et al. (6) examined 13 national and district level weightlifters performing the clean with varied weights, and their findings support those of Enoka (3). The first pull produced a peak ground reaction force (Fz) of 130% of the system weight (body weight and barbell), with the ground reaction force in the unweighted phase dropping to 85% of the system weight. The end of the second pull displayed the greatest peak Fz at 150% of the system weight, signifying the second pull as the most explosive portion of the lift.

The power clean is another training exercise that has been shown to increase an athlete's performance by imitating sport-specific movements, while concurrently utilizing explosive power (14). Cross (2) utilizes the power clean during volleyball training in order to enhance the performance of his athletes, whereas Marsit (10) uses the power clean with women basketball players to improve their productivity in competition. Although strength and conditioning coaches are utilizing the power clean in their programs, no study to date has investigated the kinetics of the power clean to see whether the same technique is needed when compared with the clean and the clean pull. Therefore, the purpose of this study is to investigate the kinetics involved in the power clean.

Methods

Experimental Approach to the Problem

Kinematic and kinetic analyses of the clean and the clean pull have been investigated thoroughly in the past. Garhammer (4), in the past, has presented an extensive kinesiological analysis of the power clean; however, no study to date has investigated the kinetics of the power clean to determine whether the same technique is needed when compared with the clean

Table 1. Subject profile of 10 male collegiate level weightlifters at California State University, Sacramento.

Subject	Mass (kg)	Height (cm)	Age (y)	Weight-lifting class (kg)	Weight-lifting experience (y)
1	80.26	168.9	23	77	4.02
2	94.54	176.5	29	84	5.00
3	68.93	172.7	24	69	2.04
4	94.77	108.3	24	94	1.06
5	108.38	185.4	28	105	3.00
6	117.9	184.2	25	105.0+	12.00
7	68.02	162.6	25	69	2.06
8	103.39	172.7	29	105	1.06
9	87.52	172.7	20	85	1.10
10	90.01	190.5	32	94	2.00

Table 2. Maximal clean, power clean 60 and 70%, and system weight (percentage power clean + weight of subject) of 10 male collegiate level weightlifters.

Subjects	Max clean (kg)	Power clean 60% (kg)	Power clean 70% (kg)	System weight, 60% (N)	System weight, 70% (N)
1	135	80	95	1,572.17	1,719.32
2	110	65	77.5	1,565.14	1,687.77
3	90	55	62.5	1,215.71	1,289.28
4	105	62.5	72.5	1,542.84	1,640.94
5	160	95	112.5	1,995.12	2,166.79
6	170	102.5	120	2,162.11	2,333.78
7	100	60	70	1,255.86	1,353.96
8	120	72.5	85	1,725.46	1,848.09
9	125	75	87.5	1,594.29	1,716.92
10	105	72.5	72.5	1,496.13	1,594.23

and the clean pull. This study will investigate the ground reaction forces of 10 collegiate weightlifters performing 2 power cleans that are 60 and 70% of their last competition maximum clean. The analysis of this data provides the magnitudes and sequences of forces applied during the power clean. Understanding the kinetics of the power clean will provide insight into the proper technique, which may aid strength and conditioning coaches in their quest of building elite athletes.

Subjects

Ten collegiate weightlifting male subjects between the ages of 18 and 30 years, in 8 bodyweight categories ranging from 56.0 to 105.0+ kg, served as volunteers for the study. Five of the subjects were part of a 3 year national championship winning team. At the time of the study, all 10 subjects were competing in local and national level weightlifting events. Subject profiles are listed in Tables 1 and 2. Written informed consent was obtained before any experimental testing. The California State University of Sacramento Institutional Review Board approved the study. The selection of the subjects was based on a minimum of 1 year of competition experience and the subject's knowledge of the rules and procedures associated with the sport of weightlifting (18). Collegiate weightlifters were selected for this study because of their familiarity with the power clean, insuring that proper technique was followed.

Kinetic and Kinematic Measurement System

An AMTI force plate (63.5 × 63.5 cm; Advanced Mechanical Technologies, Inc., Watertown, MA) was used to collect ground reaction forces of the right foot at a rate of 500 Hz. An eighth-order low-pass Butterworth filter with a 25-Hz cutoff was used to filter the kinetic data. Three cameras (Philips TC 351A) with a shutter speed of 500 Hz recorded the movements of the lifts at 60 Hz. VHS (Maxwell GX Silver T-120) tapes were used, and 3 VHS recorders (Panasonic AG 2560) collected the video data. A low-pass eighth-order Butterworth filter with an 8 Hz cut-off was used to filter the kinematic data. A 3-dimensional scaling rod was positioned in the field of view and filmed for 2 minutes before filming the subjects. The Peak Motus synchronization unit was used to match the kinetic and kinematic data. An external trigger mechanism was used to mark the kinematic data, which initiated the collection of kinetic data. The beginning of the lift was identified as when the bar began to flex. The end point of the lift was defined as full extension of the knees, with the bar resting on the clavicles and shoulders of the subject.

Experimental Protocol

The subjects were instructed to warm up with 40% of their maximal clean for 5 repetitions for 3 sets. Four reflective markers were then placed on the following anatomical sites: greater trochanter of the femur, head of fibula, lateral malleolus of the fibula, and the head of the fifth metatarsal. The subjects wore dark spandex shorts, providing a strong contrast with the reflective markers. A large black sheet was hung behind the subjects during all the lifts. The subject's right foot was placed on the force plate and placed in view of all the cameras. The bar was loaded with 60% of the lifter's last maximum competitive clean weight lift and placed over the force plate. The experimental setup is displayed in Figure 1.

Before each lift, the subject placed the bumper plates over preplaced markers on the floor to insure that the bar started at the same point during each trial. A marker was also placed on the bar for hand placement for each subject. The subjects started with 5 repetitions at 60% of their maximal lift for the clean in the last competition that took place 3 months before filming. After the 60% lift was completed, the subject rested, as another subject performed his 60% lift. The 70% lift was completed in the same manner. After the

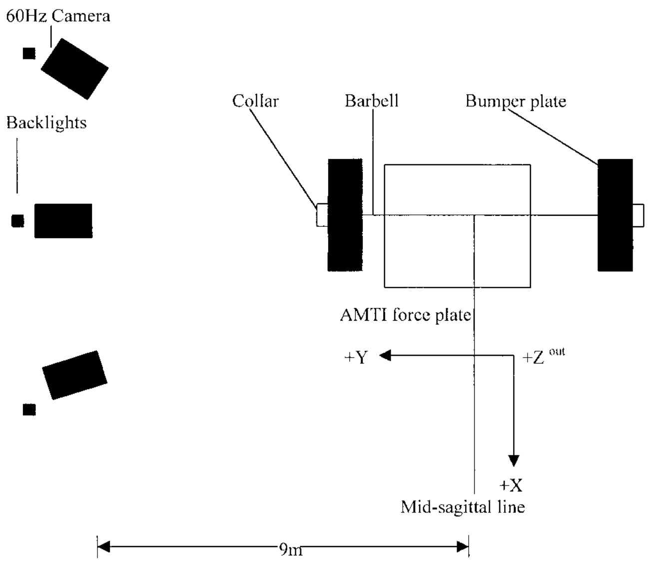

Figure 1. Superior view of cameras, force plate, and barbell used for data collection.

2 subjects were filmed for the 60 and 70% lifts, all 4 VHS videotapes were replaced, and 2 more subjects were then placed into the rotation. The moderate percentage power clean weights utilized in the study were chosen to prevent interference with the weightlifter's training schedule and to limit the likelihood of injury.

Statistical Analyses

An analysis of variance with repeated measures, with a covariance of weight and height, was used to determine whether differences occurred between each phase of the power clean for each individual percentage lift. A Tukey post hoc analysis was performed on significant results. The alpha levels were set at $p \leq 0.05$.

Results

The results revealed that all the subjects produced a significantly greater ($p < 0.05$) ground reaction force (Fz) during the first pull when compared with the unweighted phase for both percentage lifts when mass was controlled (Table 3). Also, the second pull was significantly greater ($p < 0.05$) than the unweighted phase when mass was controlled for during both the 60 and 70% power cleans. Although not significant, all 10 subjects produced a greater ground reaction force (Fz) for the second pull when compared with the first pull phase (Tables 3–5). The ground reaction force displays 3 distinct phases, first pull, unweighted, and second pull, as noted by Enoka (3) for the clean pull, followed by the catching phase, as explained by Garhammer (4) for the power clean (Figure 2).

Discussion

Previously, athletes trained 1 muscle group at a time, creating an unbalanced body structure (9, 10, 12). To-

Table 3. The system weight, peak averages, and standard deviation of ground reaction forces (Fz) during the 60 and 70% power clean lifts for all 10 subjects. System weights and forces are given in newtons. A, B, C, D, E, and F denote which movements are significant in relation to one another in each percentage lift.

System weight, 60%	First pull Fz, 60%, A	Unweighted Fz, 60%, B	Second pull Fz, 60%, C	System weight, 70%	First pull Fz, 70%, D	Unweighted Fz, 70%, E	Second pull Fz, 70%, F
1,612.48 ± 292.21	1,140.35 ± 234.50 *B	557.34 ± 140.73 *A**C	1,532.12 ± 343.79 **B	1,735.11 ± 321.99	1,188.92 ± 184.01 **E	579.71 ± 108.25 **D**F	1,512.18 ± 336.33 **E

* $p < 0.05$, ** $p < 0.01$.

Table 4. The mean peak and standard deviation of ground reaction force (Fz) and percentage of Fz/system weight during the 60% power clean for each subject. System weights and forces are given in newtons.

Subject	System weight	First pull Fz	(%)	Unweighted Fz	(%)	Second pull Fz	(%)
1	1,572.17	1,089.13 ± 18.32	69	386.64 ± 58.08	25	1,255.34 ± 43.56	78
2	1,565.14	1,068.38 ± 15.83	67	506.87 ± 52.86	32	1,388.84 ± 76.18	88
3	1,215.71	911.32 ± 43.12	58	505.72 ± 40.50	32	1,139.74 ± 61.94	73
4	1,542.84	1,325.56 ± 50.66	109	647.25 ± 86.80	53	1,604 ± 55.05	132
5	1,995.12	1,319.24 ± 16.61	86	592.59 ± 28.98	38	1,949.78 ± 50.08	126
6	2,162.11	1,628.76 ± 66.38	82	823.87 ± 73.64	41	2,239.78 ± 82.58	112
7	1,255.86	834.81 ± 27.99	39	440.13 ± 44.0	20	1,300.22 ± 28.68	60
8	1,725.46	1,199.56 ± 36.03	96	680.62 ± 86.82	54	1,648.9 ± 60.41	131
9	1,594.29	1,032.0 ± 447.10	60	610.57 ± 239.88	35	1,508.8 ± 650.93	87
10	1,496.13	994.75 ± 17.67	62	379.14 ± 65.2	23	1,315.8 ± 73.8	82

Table 5. The mean peak and standard deviation of ground reaction force (Fz) and percentage of Fz/system weight during the 70% power clean for each subject. System weights and forces are given in newtons.

Subject	System weight	First pull Fz	(%)	Unweighted Fz	(%)	Second pull Fz	(%)
1	1,719.31	1,140.60 ± 12.95	66	454.51 ± 52.30	26	1,301.4 ± 55.0	76
2	1,687.77	1,105.2 ± 20.69	65	536.21 ± 65.52	32	1,412.4 ± 31.2	84
3	1,289.28	949.87 ± 24.10	74	537.36 ± 50.99	42	1,147.2 ± 39.7	89
4	1,640.94	1,367.56 ± 47.80	83	736.43 ± 86.78	45	1,714.5 ± 74.2	104
5	2,166.79	1,381.36 ± 30.39	64	634.02 ± 28.81	29	1,985.4 ± 45.1	92
6	2,333.78	1,740.96 ± 39.62	75	850.34 ± 65.77	36	2,336.4 ± 77.8	100
7	1,353.96	867.02 ± 29.73	64	426.90 ± 31.15	32	1,372.7 ± 38.8	101
8	1,848.09	1,270.92 ± 27.18	69	584.54 ± 73.49	32	1,743.2 ± 40.6	94
9	1,716.92	1,024.10 ± 45.03	60	529.88 ± 58.15	31	1,514.9 ± 105.0	88
10	1,594.23	1,021.2 ± 34.57	64	373.96 ± 28.48	23	1,383.1 ± 24.4	87

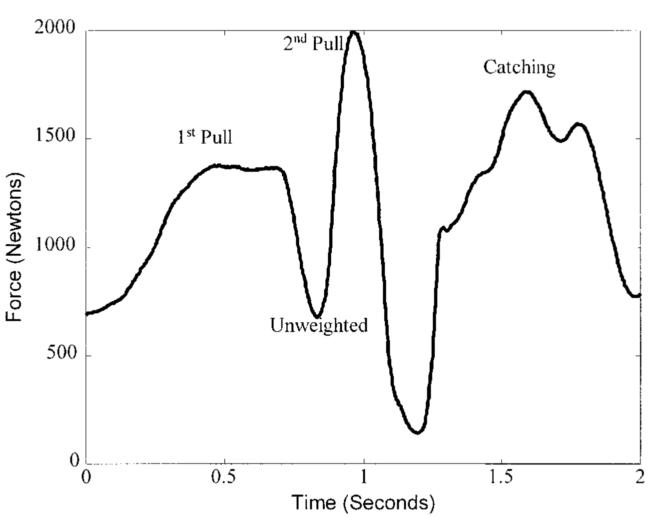

Figure 2. The ground reaction force (Fz) of subject 5's single trial 70% lift, displaying the first pull in the beginning of the lift, with the first peak, followed by the unweighted phase, exhibited by a decline, and ending with the greatest magnitude of force in the final second pull, shown by the ending peak.

day, weightlifting has evolved from this approach by implementing the power clean into athletic training programs in order to strengthen the body in a more balanced and natural fashion (8, 11). This philosophy has grown with the increasing number of strength and conditioning coaches involved in the sport today (2, 9, 10, 12, 14, 15). Therefore, the objective of this study is to further add to the literature by characterizing and describing the ground reaction forces occurring when a power clean is performed.

The kinetic analysis of the power clean revealed 4 distinctive phases (first pull, unweighted, second pull, and catching), as previously described by Garhammer's (4) kinesiological evaluation. When investigating the ground reaction forces of the power clean for the 60% power clean lift, we found that the second pull produced the greatest Fz/system weight percentage (96.9 ± 26.16%) when compared with the first pull Fz/system weight percentage (72.8 ± 20.54%) and was significantly greater than the unweighted (35.30 ± 11.62%) phase. The subjects performing the 70% power clean were observed to produce similar results, with the second pull producing the greatest Fz/system weight percentage (91.50 ± 8.57%) when compared with the first pull (68.40 ± 6.95%) and significantly greater than the unweighted (32.80 ± 6.71%) phase. Enoka (3) found similar results when examining the clean pull. Enoka found that the subjects displayed a much greater peak force during the second pull compared with the unweighted and the first pull, suggesting that more force is needed during the second pull. Hakkinen et al. (6) further support the theory that the second pull is the most important phase in the pulling lifts (clean pull, clean, and power clean), when investigating the clean.

Hakkinen et al. (6) further suggested that a weightlifter's ground reaction force would decrease as the system weight percentages increased. As a group, the subjects in this study produced a slightly greater ground reaction force (Fz) in the first pull and unweighted phases of the 70% when compared with the 60% power clean. However, the peak ground reaction force (Fz) for the second pull decreased during the 70% compared with the 60% lift. Only slight differences were seen, and this may be attributed to the fact that the weight percentages selected for this study were too close in weight, not creating enough division to exhibit a larger difference in either direction.

Athletes today are becoming faster and stronger, while coaches are trying to find any edge that will help to create the most optimal machine. A biomechanical analysis of the power clean, looking at 10 collegiate weightlifters, revealed that the first pull had the longest time period, with the second pull producing the greatest peak ground reaction force (Fz), as seen in previous studies (3, 6). Because the power clean mimics the clean portion of the clean and jerk, with minor differences, the assumption is made that a weightlifter needs to produce more force during the second pull compared with the first pull. This study found that the first pull is a more controlled and slower movement, which involves lifting the bar from the floor to the knees, where the lifter then realigns himself or herself before attempting to start the second pull. The explosive or second pull is more of a ballistic type motion that causes the hips, back, and legs to thrust vertically with a greater amount of speed, producing a greater amount of force in a much smaller time period (4). The power clean was observed as having the same biomechanical characteristics as the clean pull and the clean.

Practical Applications

Investigating the dynamics associated with the power clean may aid coaches and athletes by identifying the biomechanical characteristics that are essential to achieve a flawless lift. This analysis of the power clean may provide some valuable feedback for the coach and athlete, that otherwise may have been missed when assessing a lifting technique. Weightlifters and other power athletes perform at high levels, and any additional evaluation using kinetic data may provide information that will make a difference between a losing team and a winning one.

References

1. BURKHARDT, E. Ground reaction forces during weightlifting. *Weightlifting USA* 13(2):22–23. 1995.
2. CROSS, T. Rationale and coaching points for Olympic style lifting to enhance volleyball performance. *Natl. Strength Cond. Assoc. J.* 15(6):59–61. 1993.
3. ENOKA, R. The pull in Olympic weightlifting. *Med. Sci. Sports* 11:131–137. 1979.
4. GARHAMMER, J. Bridging the gap: Power clean, kinesiological evaluation. *Natl. Strength Cond. Assoc. J.* 6(3):40, 61–63. 1984.
5. GARHAMMER, J. Biomechanical profiles of Olympic weightlifters. *Int. J. Sport Biomechanics* 1:122–130. 1985.
6. HAKKINEN, K., H. KAUHANEN, AND P. KOMI. Biomechanical changes in the Olympic weightlifting technique of the snatch and the clean & jerk from submaximal to maximal loads. *Scand. J. Sports Sci.* 6:57–66. 1984.
7. JOHNSON, J. Teaching the power clean and the hang power clean. *Natl. Strength Cond. Assoc. J.* 4(4):52–54. 1982.
8. JONES, A. The hang clean. *Natl. Strength Cond. Assoc. J.* 13(6): 50–51. 1991.
9. JUDGE, L. Preseason preparation for the collegiate shotputter. *Natl. Strength Cond. Assoc. J.* 14(3):20–26. 1992.
10. MARSIT, J. Strength and conditioning for women's basketball. *Strength Cond.* 16(1):70–74. 1994.
11. MEDVEDEV, A. Three periods of the snatch and clean and jerk. *Natl. Strength Cond. Assoc. J.* 10(6):33–38. 1988.
12. PARKER, J. Modern principles for the young football player. *Natl. Strength Cond. Assoc. J.* 14(3):28–31. 1992.
13. REISER, R., S. SMITH, AND R. RATTAN. Science and technology to enhance weightlifting performance: The Olympic program. *Strength Cond.* 18(4):43–51. 1996.
14. STONE, M. Explosive exercise and training. *Natl. Strength Cond. Assoc. J.* 15(3):7–15. 1993.
15. STONE, M., A. FRY, M. RITCHIE, L. STOESSEL-ROSS, AND J. MARSIT. Injury potential and safety aspects of weightlifting movements. *Strength Cond.* 16(3):15–21. 1994.
16. TAKANO, B. Coaching optimal technique in the snatch and the clean and jerk: Part I. *Natl. Strength Cond. Assoc. J.* 9(5):50–59. 1987.
17. TAKANO, B. Coaching optimal technique in the snatch and the clean and jerk: Part III. *Natl. Strength Cond. Assoc. J.* 10(1):54–56. 1988.
18. USA WEIGHTLIFTING. *USA Weightlifting Official Rulebook.* Colorado Springs: USA Weightlifting, 1997.
19. WHALEY, O., AND R. MCCLURE. Another perspective on teaching the pulling movements. *Strength Cond.* 19(2):58–61. 1997.

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