UNIVERSITY OF WISCONSIN-LA CROSSE

Graduate Studies

KINETIC COMPARISON OF THE POWER DEVELOPMENT BETWEEN THE HANG CLEAN, JUMP SHRUG AND HIGH PULL

A Manuscript Style Thesis Submitted in Partial Fulfillment of the Requirements for the Degree of Degree of Master of Science in Human Performance

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May, 2012

KINETIC COMPARISON OF THE POWER DEVELOPMENT BETWEEN THE HANG CLEAN, JUMP SHRUG, AND HIGH PULL

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ABSTRACT

Suchomel, T.J. Kinetic comparison of the power development between the hang clean, jump shrug, and high pull. MS in Human Performance, May 2012, 57pp. (G. Wright)

PURPOSE: To compare the kinetics of the hang clean (HC), jump shrug (JS), and high pull (HP) when performed at different relative loads. **METHODS:** Seventeen men with at least 2 years of training experience with the HC performed 3 repetitions each of the HC, JS, and HP exercises at relative loads of 30%, 45%, 65%, and 80% of their 1 repetition maximum (1RM) HC on a portable force platform over 3 different testing sessions. **RESULTS:** Significant effects for exercise, load, and exercise x load interaction existed. The JS produced a greater PPO than the HC and HP ($p < 0.001$) and the HP produced a greater PPO than the HC ($p < 0.01$). PPO at 45% 1RM was greater than PPO at 65% ($p = 0.022$) and 80% 1RM ($p = 0.027$), but not significantly different than PPO at 30% 1RM ($p = 0.438$). The JS produced the greatest PPO at each load examined and was followed in order by the HP and HC. **CONCLUSION:** Strength and conditioning coaches should consider implementing the JS and HP into their training regimens. To optimize power production, loads at approximately 45% 1RM HC should be used for both the JS and HP.

ACKNOWLEDGEMENTS

I would like to thank Dr. Glenn Wright, Dr. Thomas Kernozek, and Dennis Kline for serving as members of my thesis committee. To Dr. Wright, thank you for reading and revising all of the drafts that I have sent you over the last two years. To Dr. Kernozek, thank you for giving me the opportunity to serve as your Graduate Assistant in the biomechanics lab and allowing me to participate in the many research studies that took place in the lab over the past two years. To Dennis Kline, thank you for providing me with many different ideas that have challenged the way I have viewed the exercise and sports science field. You have all driven me to become a better student and researcher in the exercise and sports science field.

Thanks go to Chris Dodge. You provided the force platform and other equipment necessary for the completion of this project. Because of your help, I was able to collect all of the data needed to calculate the variables that were compared in this study.

I would also like to thank the other Human Performance graduate students. Thank you for your encouragement and your assistance during the completion of this project. I hope that I have been as much of a positive influence on all of you as you have been on me. I look forward to extending our relationships past graduate school and I hope to work with all of you in some aspect in the future.

To my parents, I really appreciate all of the encouragement you have given me while I have been completing this project. If it was not for you, I would not have been able to make it through this.

Last, but certainly not least, I would like to thank the subjects who participated in this study. Without all of you, this study would not have been possible.

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INTRODUCTION

It has been well documented that a strong relationship exists between the ability of an athlete to develop high levels of muscular power and their success in sporting events (1, 4-7, 11, 12, 14-16, 18, 20, 21, 23-26, 28-31). Furthermore, many coaches and researchers believe that the ideal stimulus for improving muscular power is utilizing methods that produce maximal power with sports specific movements (24). Common movements in sports, such as sprinting and jumping, require an athlete to produce high amounts of power. Thus, the focus of many strength and conditioning practitioners is the development of lower body muscular power. By training lower body power, practitioners hope to improve the overall performance of athletes in sports competitions.

The power clean and its variations are commonly used to train lower body muscular power (3, 4, 8, 13, 15, 16-21, 23-25, 29-31). There are several phases to this technical lift which include the starting position, first pull, second pull, and catch phase. The starting position has the athlete stand with their feet flat on the floor shoulder width apart, shins close to the bar, hips lower than the shoulders, arms fully extended, back flat, shoulders over the bar, and hands grasping the bar in an overhand grip. The first pull movement begins when the athlete lifts the bar off the floor and begins raising their hips and shoulders while keeping their arms extended while their shoulders are over the bar. The second pull begins when the bar passes the knees and requires the athlete to explosively pull the bar vertically while the hip, knee, and ankle joints completely extend in a well sequenced explosive jumping movement. In addition, the athlete shrugs their shoulders and keep their elbows high allowing them to elevate the bar. The catch phase requires the athlete to rapidly rotate their elbows under the bar, while projecting them forward and keeping them high to catch the bar across their shoulders in a semi-squat position (12, 13, 15, 17, 21, 31).

By implementing the power clean and its variations into training programs, strength and conditioning practitioners train lower body power, highlighted by the explosive extension of the hip, knee, and ankle joints (23). The second pull phase, which produces the greatest ground reaction force and power output during Olympic style lifts (12, 13, 14, 20), is similar to many sport movements and therefore is the phase that classifies the power clean and its variations as sports specific (20). To emphasize power development during the second pull phase, practitioners often prescribe power clean variations that are performed from the hang position. Of these hang variations, the hang clean (HC), may be the most commonly used. This exercise can be very beneficial to an athlete because it requires the athlete to produce high levels of force and power to complete the exercise. However, the catch phase of the HC, which is identical to that of the power clean, increases the skill necessary to complete the lift successfully. Thus, despite being a highly beneficial exercise, the HC may be more difficult to teach an athlete as compared to a variation that does not include the catch phase. It has been suggested that it may be essential to substitute other less technical exercises to train lower body muscular power (1, 20). This raises the question, are there power clean variations that do not include the catch phase that can be used to effectively train lower body muscular power?

Two other variations of the power clean are the jump shrug (JS) and high pull (HP). Similar to the HC, the JS and HP are both performed from the hang position and are used to train lower body power. However, little is known about the extent to which the JS and HP exercises can train lower body muscular power. Thus, it is unknown how these exercises compare to the power produced by the HC.

The HC, JS, and HP variations of the power clean are all vertical pull exercises that are used to train lower body power. The nature of these exercises is similar in that they are all dependent on a powerful shrug of the shoulders and triple extension of the hip, knee, and ankle joints. However, the HC is a technical exercise that includes the catch phase, making it more complex and time-consuming for the practitioner to teach an athlete on how to properly execute the lift (17). In contrast, the JS and HP are less technical exercises that are used as part of the teaching progression to perform the power clean (17, 21), which may make these exercises easier to learn. Due to a lack of research, it is unknown how effective the JS and HP are at producing lower body power. It is possible that the maximal power production provided by the JS and HP may be similar or greater than that of the HC because they allow the athlete to focus on the second pull instead of dipping under the bar to complete the catch phase.

Much research has sought to identify the optimal load that produces the greatest power output during the power clean and its variations (5, 8-10, 23, 25). Comfort et al. (5) concluded that the peak power output during the power clean occurs at 70% 1-repetition maximum (1RM), while Cormie et al. (8-10) determined that the peak power output during the power clean occurs at 80% 1RM. In addition, Kawamori et al. (23) reported that the peak power output during the HC exercise occurred at 70% 1RM.

Kilduff et al.'s (25) findings differed slightly with peak power output occurring at 80% 1RM for the HC exercise. However, several studies reported no significant difference between the optimal load and 60-80% 1RM (5) or 50-90% 1RM (8, 23, 25).

Previous research suggests that it may be essential that the strength and conditioning practitioner selects exercises that maximize power output during the movement that is being trained (24). Furthermore, by identifying and training with the ideal load for a specific exercise, athletes will be able to optimally improve their muscular power and as a result, their overall athletic performance (23). Therefore, the purpose of this study is to compare the kinetics of the HC, JS, and HP when performed at different loads relative to a 1RM HC.

METHODS

Experimental Approach to the Problem

The present study was designed to compare the peak force (PF), peak velocity (PV), and peak power output (PPO) produced during the HC, JS, and HP exercises at different relative loads (30, 45, 65, 80%) of each subject's 1RM HC. Subjects completed a single familiarization session and three different testing sessions. Each session was separated by a minimum of two days with a maximum of seven. The familiarization session was used to obtain the subject's 1RM of the HC exercise and to familiarize the subjects with the JS and HP exercises. During each testing session, subjects completed randomized sets of one of the exercises (HC, JS, or HP) on a force platform while the vertical ground reaction forces at different relative loads were collected. All exercises were performed using the same countermovement hang technique as described by Kawamori et al. (23).

Subjects

Seventeen athletic males with a minimum of two years of previous training experience with the HC exercise, but no previous competitive weightlifting experience, agreed to participate in the present study. The physical and performance characteristics of the subjects are displayed in Table 1. All subjects read and signed an informed consent form prior to participating in any activity in this investigation, in compliance with the approval from the Institutional Review Board at the University of Wisconsin-La

Crosse. Subjects were asked to refrain from physical activity that may affect testing performance, the consumption of alcohol, caffeine, and other ergogenic aids at least 24 hours prior to each testing session.

Table 1. Physical and performance characteristics of the subjects

Variable	Mean ± SD
Age (y)	21.59 ± 1.28
Height (cm)	180.87 ± 6.27
Body Mass (kg)	87.13 ± 15.60
1RM Hang Clean (kg)	111.12 ± 20.40
Hang Clean Experience (y)	3.91 ± 1.23

n = 17

One Repetition Maximum (1RM) Hang Clean Testing

Each subject's 1RM HC was determined by using the protocol previously established by Winchester et al. (32) using technique previously described by Kawamori et al. (23). Prior to performing any maximal HC attempts, each subject completed a standardized dynamic warm up lasting approximately 8 minutes, and several submaximal exercise sets. Briefly, the HC exercise started from a standing position with the subject holding the bar using an overhand grip. Subjects then lowered the bar down their thighs to just above knee level, lifted the bar explosively upward, and caught the bar across their shoulders in a semi-squat position. The HC repetition was termed as unsuccessful if the researcher observed that the subject's upper thigh fell below parallel to the floor during the catch phase. After the subject's 1RM HC was established, subjects were familiarized with the technique of the JS and HP exercises. The JS and HP required the athlete to start in a standing position and lower the bar to their thighs until the bar was just above their knees, identical to the beginning of the HC. The JS required the athlete to explosively jump with the barbell while violently shrugging their shoulders (13, 17, 21). A successful repetition of the JS required the athlete to leave the surface of the force platform. After the bar was lowered to a position just above their knees, as described above, the HP required the athlete to lift the bar explosively upward, shrug the shoulders and then drive their elbows upward, and elevate the barbell to chest height (13, 21). A successful HP repetition was determined if the athlete lifted the bar explosively upward and elevated the barbell to chest height. The hang position and exercises are displayed in Figures 1, 2, 3, and 4.

Power Testing

A dynamic warm up (e.g. stationary cycling, lunges, countermovement jumps, etc.) and light exercise sets (e.g. 30, 50% 1RM HC) of the exercise that was to be performed that day were performed prior to testing. They completed three maximal effort repetitions at each of the relative loads (30, 45, 65, and 80% of their 1RM HC) in a randomized order using the exercise of the day. Therefore, each testing session required the subject to perform 12 total repetitions. The same randomized order of relative loads was used during each testing session with the different exercises. Due to the large number of repetitions, only one exercise (HC, JS, or HP) was tested per visit in a randomized order to prevent fatigue. Sixty seconds of rest was provided between each repetition (16) while two minutes were provided between each load. The bar was placed on the safety bars of a squat rack in between all repetitions to prevent fatigue. All repetitions of each exercise were performed on a portable Kistler Quattro Jump force platform (Type 9290AD, Kistler, Winterthur, Switzerland) and sampled at 500Hz. Subjects were encouraged to complete each repetition with maximal effort.

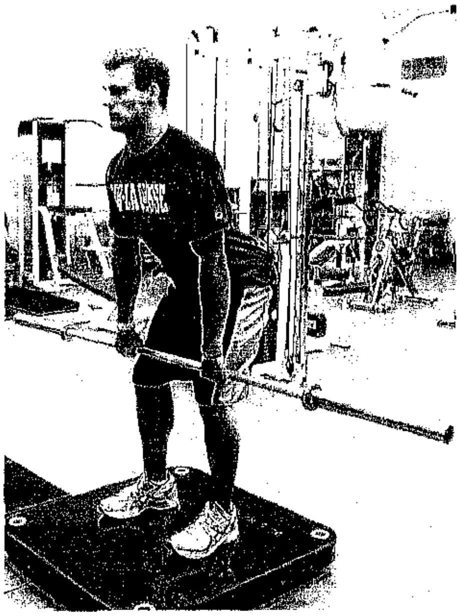

Figure 1. Barbell lowered to the countermovement hang position.

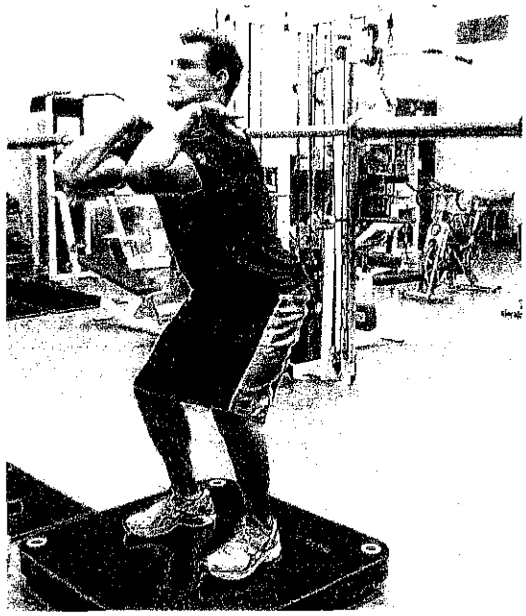

Figure 2. Finishing position of the hang clean.

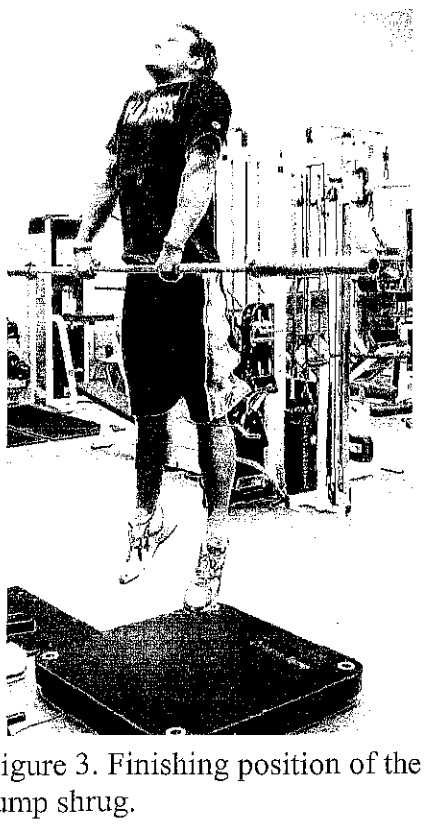

Figure 3. Finishing position of the jump shrug.

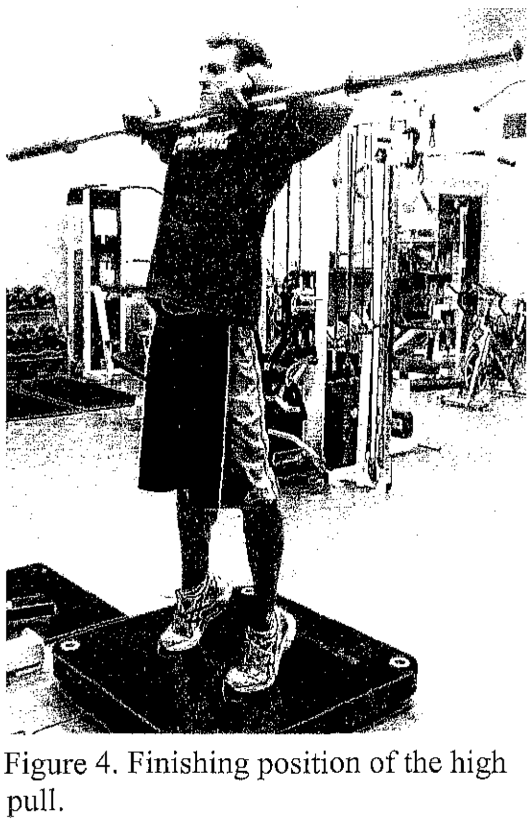

Figure 4. Finishing position of the high pull.

Data Analysis

Peak force, PV, and PPO of the center of mass of the lifter plus bar system were calculated from the vertical ground reaction forces of the HC, JS, and HP. The greatest PF, PV, and PPO values produced by each subject during the HC, JS, and HP at each load were used for comparison. Vertical ground reaction forces (GRF_{Vert}) (Newtons) of the lifter plus bar system were measured with the force platform. Instantaneous acceleration (A_n) of the lifter plus bar system was then determined by dividing the vertical ground reaction force by the mass of the lifter plus bar system ($Mass_{System}$) (kilograms) and then subtracting the acceleration due to gravity (G). Instantaneous velocity (V_n) of the lifter plus bar system was determined by taking the velocity from the previous sample (V_{n-1}) and adding it to the product of the average acceleration (meters per second squared) of the previous (A_{n-1}) and current (A_n) samples and the change in time (ΔT) between samples (seconds). Instantaneous power output (P_n) (Watts) was determined by the product of the vertical ground reaction force and the instantaneous velocity (meters per second) of each sample. Each equation is listed below.

$$G = 9.8 \text{ m} / \text{s}^2$$

$$A_n = [GRF_{Vert} / Mass_{System}] - G$$

$$\Delta T = 0.002 \text{ s}$$

$$V_n = V_{n-1} + [((A_n + A_{n-1}) / 2) * \Delta T]$$

$$P_n = GRF_{Vert} * V_n$$

Statistical Analysis

All data are reported as the mean ± standard deviation. A series of 3 (exercise) x 4 (load) repeated measures ANOVAs were used to compare the differences in the PF, PV, and PPO between the HC, JS, and HP exercises at the various (30, 45, 65, 80% HC 1RM) loads. When necessary, post hoc analyses were performed using the Bonferroni technique. For all statistical tests the alpha value was set at 0.05. All statistical analysis was performed using SPSS 19.1 (SPSS Inc., Chicago, IL).

RESULTS

Exercise

Exercise main effect results are displayed in Table 2. Significant differences in PF were identified between the HC, JS, and HP exercises ($p < 0.001$). Post hoc analysis revealed a significantly greater PF during the JS compared with both the HC and the HP ($p < 0.001$). However, no significant difference in PF existed between the HC and HP variations of the power clean ($p = 0.338$).

Significant differences in PV occurred between the HC, JS, and HP exercises ($p < 0.001$). Post hoc analysis revealed a significantly greater PV during the JS compared to both the HC and HP ($p < 0.001$). In addition, the PV of the HP was significantly greater than the HC variation ($p < 0.001$).

Significant differences in PPO occurred between the HC, JS, and HP exercises ($p < 0.001$). Post hoc analysis revealed a significantly greater PPO during the JS compared to both the HC and HP ($p < 0.001$). In addition, the PPO of the HP was significantly greater than the HC variation ($p < 0.01$).

Table 2. Exercise main effects for peak force, peak velocity, and peak power output (mean ± SD): n = 17.

Exercise	Performance Variables		
	PF (N)	PV (m/s)	PPO (W)
HC	3270.97 ± 698.15	1.70 ± 0.28	4179.95 ± 1182.29
JS	3603.26 ± 678.06*	2.17 ± 0.31*	5899.32 ± 1367.02*
HP	3338.69 ± 710.06	1.91 ± 0.28^{+}	4839.41 ± 1225.94^{+}

PF = peak force; PV = peak velocity; PPO = peak power output; HC = hang clean; JS = jump shrug; HP = high pull
* = significantly different from HC and HP
+ = significantly different from HC

Load

Load main effects are displayed in Table 3. Significant differences in PF were observed between the different loads during the HC, JS, and HP exercises ($p < 0.001$). The load of 80% 1RM displayed the highest PF. This was followed in order by 65%, 45%, and finally 30% 1RM. Post hoc analysis revealed that the exercise load of 30% 1RM yielded significantly lower PF than 45% ($p = 0.011$), 65% ($p < 0.001$), and 80% 1RM ($p < 0.01$). However, no significant differences in PF existed between 45%, 65%, and 80% 1RM ($p > 0.05$).

Significant main effects in PV occurred between different loads during the HC, JS, and HP exercises ($p < 0.001$). The greatest PV occurred at 30% 1RM. This was followed in order of magnitude by 45%, 65%, and 80% 1RM. Post hoc analysis revealed that 30% ($p < 0.001$) and 45% 1RM ($p < 0.001$) were both significantly greater than 65% and 80% 1RM, with no significant difference between 30% and 45% 1RM ($p = 0.873$). In addition, 65% 1RM produced a significantly greater PV than 80% 1RM ($p = 0.041$).

Significant main effects in PPO occurred between different loads during the HC, JS, and HP exercises ($p < 0.01$). The greatest PPO occurred at 45% 1RM. This was followed in order by 30%, 65%, and 80% 1RM. Post hoc analysis revealed that the PPO at 45% 1RM was significantly greater than PPO that occurred at 65% ($p = 0.022$) and 80% 1RM ($p = 0.027$). However, PPO at 45% 1RM was not significantly different from PPO at 30% 1RM ($p = 0.438$). No other significant differences existed between PPO that occurred at 30%, 65%, and 80% 1RM ($p > 0.05$).

Table 3. Load main effects for peak force, peak velocity, and peak power output (mean ± SD): n = 17.

Load	Performance Variables		
	PF (N)	PV (m/s)	PPO (W)
30% 1RM	3214.80 ± 701.00	2.09 ± 0.40$^{+†}$	5063.69 ± 1723.82
45% 1RM	3424.31 ± 708.90*	2.04 ± 0.34$^{+†}$	5233.99 ± 1553.23$^{+†}$
65% 1RM	3487.15 ± 710.75*	1.83 ± 0.22†	4900.15 ± 1235.58
80% 1RM	3490.96 ± 690.29*	1.73 ± 0.25	4693.73 ± 1167.96

PF = peak force; PV = peak velocity; PPO = peak power output
* = significantly different from 30% 1RM
+ = significantly different from 65% 1RM
† = significantly different from 80% 1RM

Exercise and Load Interaction

Significant interactions for PF ($p < 0.01$), PV ($p < 0.001$), and PPO ($p < 0.001$) were observed between the HC, JS, and HP exercises performed at different loads. The exercise x load interaction effects for PF, PV, and PPO are displayed in Figure 5. At every exercise load, the order of highest PF, PV, and PPO remained the same with the JS being the greatest followed in order by the HP and the HC. Given that the order of exercises remained the same (i.e. JS > HP > HC) in all variables measured throughout the loading spectrum within this study, the interaction appeared to be a result of the load. Thus, the greatest differences in PF, PV, and PPO between the exercises occurred at the lighter loads (30% and 45% 1RM), but these differences were less observable at the heavier loads (65% and 80% 1RM).

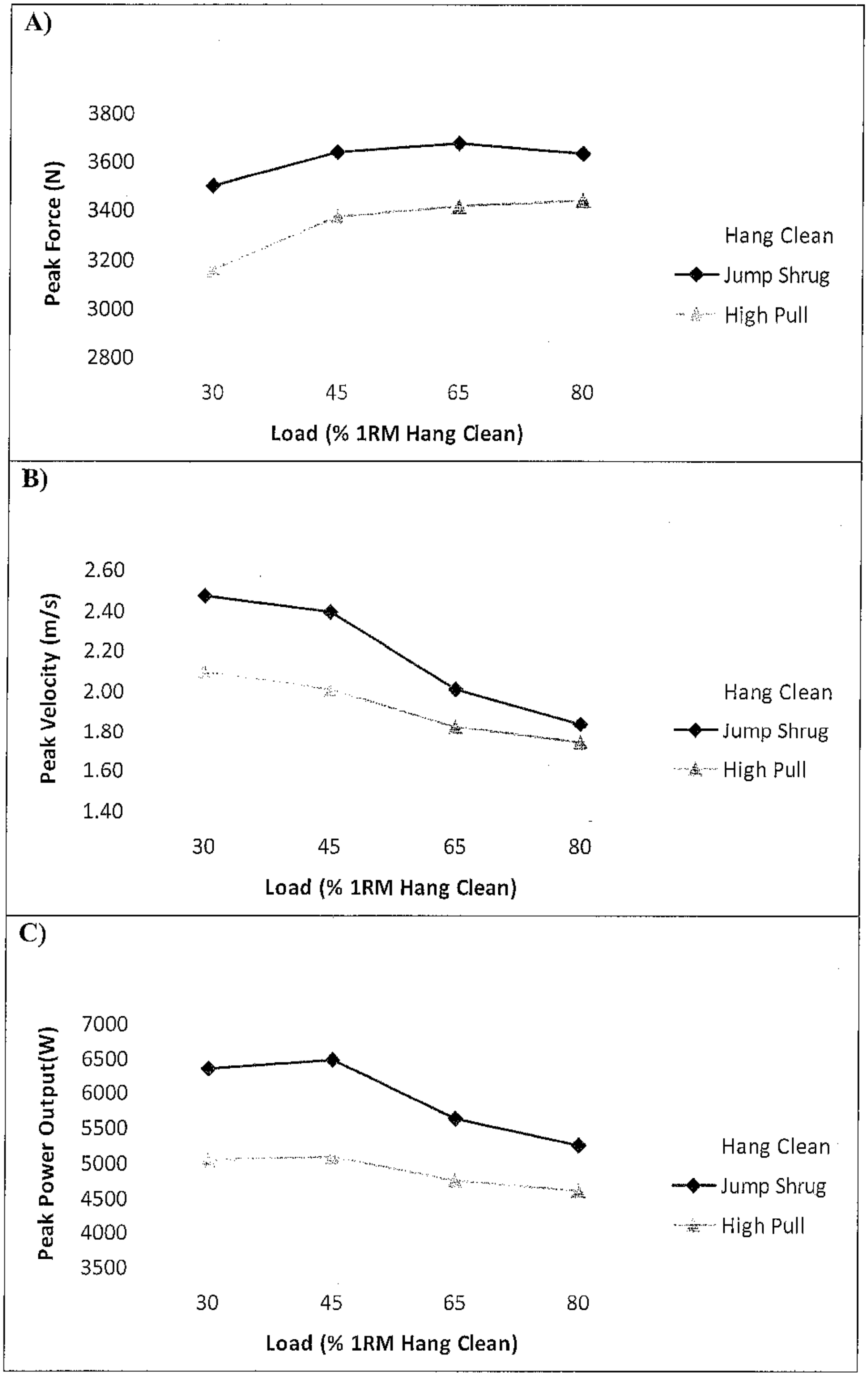

Figure 5. Exercise and load interactions for A) peak force, B) peak velocity, and C) peak power output for the hang clean, jump shrug, and high pull exercises. n = 17.

DISCUSSION

It is likely that the ideal stimulus for improving muscular power involves training in a way where maximal power production is produced during sports specific movements (24). The main purpose of this study was to compare the kinetics of the HC, JS, and HP when performed at different relative loads. The main findings of this study were threefold. First, differences in PF, PV, and PPO existed between the HC, JS, and HP. Second, there were differences in PF, PV, and PPO between the different exercise loads. Finally, there were interactions between the exercise (HC, JS, and HP) at specific loads for all of the variables examined in the current study. As hypothesized, the JS produced the greatest PF, PV, and PPO. These values were followed in order by the HP and HC.

Previous research has documented that success in sports appears to be strongly related to the ability of athletes to produce high levels of muscular power (1, 4-7, 11, 12, 14-16, 18, 20, 21, 23-26, 28-31). The HC, JS, and HP variations of the power clean are vertical pull exercises that are used to train lower body power. The nature of these exercises is similar in that they are all dependent on a powerful shrug of the shoulders and triple extension of the hip, knee, and ankle joints. However, our results indicate that the JS and HP allowed for greater maximal power production by the athletes as compared to the HC. It has been suggested that if athletes train using exercises that allow them to improve their muscular power, their overall athletic performance will also improve (23).

The data of the current study indicate that the JS produced a greater PF, PV, and PPO than both the HC and HP. More specifically, the PF during the JS exercise was 9.7% and 7.6% greater than the HC and HP exercises respectively. The PV during the JS was 24.3% and 12.8% greater than the HC and HP respectively. Finally, the PPO during the JS was 34.1% and 19.7% greater than the HC and HP exercises respectively. In addition, the HP produced a greater PV and PPO than the HC. The PV and PPO during the HP were 11.6% and 14.6% greater than the HC respectively. Because power output is the product of force and velocity developed during these training exercises, it is no surprise that the exercise that produced the greatest PF and PV was also the exercise that produced the greatest PPO. Since we did not examine loads above 80% 1RM, we do not know if this relationship would be present with heavier loads. However, it is likely that while exercise load increases, PF will continue to increase while PV will decrease.

Our results suggest that the largest contributing factor to the PPO of the JS and HP was the velocity lifter plus bar system during the movement. This seems logical since the JS and HP are more ballistic in nature than the HC. Our findings are supported by Newton et al. (28) reported that the ballistic movement of a bench press throw, where the bar was released at the end of the range of motion, resulted in a greater velocity than a traditional bench press performed explosively. In the current study, part of the criterion for a successful repetition of the JS was that the feet of the athlete had to leave the platform during the movement as determined by observing the force-time curve immediately following the repetition. It is likely that this criterion required the athlete's muscles to maintain higher force production throughout the entire range of motion, leading to a higher movement velocity (28). Therefore, the ability to produce a higher velocity at all loads with the JS, may be related to a greater need to focus on producing enough force and a fast enough velocity to leave the platform rather than focusing on what the upper limbs must do to catch the bar.

It is possible that the catch phase of the HC detracts from the PPO when athletes are not experts in the technique of the HC. Since the catch phase follows the point where the hip, knee, and ankle joints should be fully extended and the majority of the work has been completed (13, 14), it is possible that the athlete may not produce maximal vertical ground reaction forces, resulting in a reduction in maximal power output (20). It is interesting that our results indicate that the HP, with the pulling movement of the arms that brings the barbell to chest level to begin the catch phase, was always greater than the HC in all variables measured. Even more interesting, the JS, an exercise that does not perform any movement similar to the catch phase, was always superior to both the HC and HP (i.e. JS > HP > HC) in all variables measured.

It may be recommended to substitute less technical exercises to train lower body muscular power (1, 20). By training with the JS and HP exercises, athletes with limited experience or imperfect technique with the HC may still be able to effectively produce high levels of force, velocity, and power that appear to be important in sports performance. Furthermore, this may attenuate a potentially longer learning period, which is typical of the HC or power clean variation that includes the catch phase (17). By using the JS and HP instead of the HC in this instance, there may be an increase in quality training time towards lower body muscular power, which will likely improve the athlete's overall athletic performance.

As previously mentioned, it is essential that strength and conditioning coaches select exercises that allow their athletes to produce maximal power in the movement that is being trained. However, it is equally important for the practitioner to identify the loads that allow for maximal power production. Because many sports require high power output and explosiveness, it is preferred that athletes train at optimal loads so that the greatest stimulus for improved power output is provided (20, 24, 26, 27). By training at the ideal load for each exercise, athletes will be able to optimally improve their muscular power and furthermore, their overall performance (23).

The main effects of load in the present study indicated that the athletes produced the greatest PF, PV, and PPO values at loads of 80%, 30%, and 45% 1RM respectively. If a strength and conditioning professional wants to increase the maximal force production of their athletes, it is logical for a strength training program to use loads of 80% 1RM or higher with any of these exercises (2). All exercises examined in this study produced the highest PF at the 80% load. While the greatest PF was produced by the JS, any of these exercises could be utilized during a strength phase of the annual training plan. However, if improving the velocity of the movement is the goal, it may be essential for the practitioner to use much lighter loads (i.e. 45% 1RM or lower). This concept is supported by Cormie et al. (8) who found that the peak velocity for the power clean, jump squat, and squat occurred at 30% 1RM or lower for each exercise. It should be noted that their study measured bar velocity during the power clean as compared to the velocity of the lifter plus bar system found within this study. It is interesting that PV changed very little across the load continuum for the HC in our study as compared to the differences in PV across the loads for the HP and even more for the JS. This would suggest that if an athlete is training to increase the PV of the triple extension movement, the JS or HP would be preferred exercises, especially at the lower loads, than utilizing the HC for this purpose. If strength and conditioning professionals want to improve the power development of their athletes, it is important to use the optimal load with the exercise that allows the athlete to produce a high PPO (20, 24, 26, 27). In the present study, the highest PPO for the HC was found at 65% 1RM. This finding is supported by previous research that has indicated that the optimal load for the HC and power clean exercises occurred at either 70% (5, 23) or 80% 1RM (8-10, 25). However, it should be noted that several studies observed that there was no significant difference between the optimal load and 60-80% 1RM (5) or 50-90% 1RM (8, 23, 25), which makes the optimal load found within this study comparable to previous research. Unlike the HC exercise, the load that produced the highest PPO for both the JS and HP occurred at 45% 1RM. Further, the PPO produced by the HP and JS at all loads were higher than the PPO produced at the optimal load for the HC. To our knowledge, this is the first study to assess and compare the optimal load for the JS or the HP, making it difficult to compare our results to previous research.

Analysis of the interaction between the exercises and loads revealed that the greatest PF, PV, and PPO at each load were produced by the JS. This was followed in order by the HP and HC at all loads. The greatest differences in PF, PV, and PPO between the exercises were at the lighter loads of 30% and 45% 1RM. However, the differences between exercises were smaller at the heavier loads of 65% and 80% 1RM. This may be due to technique breakdown during repetitions with heavier loads. Our findings indicate that if strength and conditioning professionals are attempting to train their athletes at PPO, they should consider implementing the JS and HP with loads at approximately 45% 1RM of the HC.

The current study did not investigate the entire loading spectrum for (0-100% 1RM) for each exercise. Therefore, it is unclear whether the optimal loads for the HC, JS, and HP reported within this study are the true optimal loads for each exercise. A second limitation of this study may have been the population selected. Athletic males with at least two years of previous experience with the HC were asked to participate in this study. That being said, no women, trained or untrained, were sought out as subjects. However, the subjects in the current study are part of a population that has been frequently examined throughout the literature and therefore, the authors felt that this population may best allow for comparison with other studies.

The true optimal load for each exercise may be similar to those reported within this study, but it is recommended that future research may consider the use of smaller loading increments to better determine the optimal load for each exercise. Future research may consider the use of different populations, such as untrained men and both trained and untrained women, while comparing the HC, JS, and HP. To accurately determine how well each of these exercises trains lower body power, future research should consider analyzing the HC, JS, and HP using 3D motion analysis equipment to determine to what extent the hip, knee, and ankle joints extend during the second pull movement.

Practical Application

The results of this study may assist strength and conditioning practitioners in selecting exercises that maximize peak power production during training that may benefit athletic movements that require high levels of muscular power. Since the JS and HP variations of the power clean exercise were superior to the HC in producing force, velocity, and power of the lifter plus bar system over the entire range of loads examined, it is suggested that strength and conditioning practitioners should consider implementing the JS and HP exercises into their training regimens. The JS and HP can be used as primary methods to improve lower body muscular power, but should also be used to complement exercises that are already being utilized to improve lower body muscular strength and power. To optimize power production with both the JS and HP exercises, practitioners should consider using loads at approximately 45% of each athlete's 1RM HC.

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APPENDIX A

INFORMED CONSENT FORM

INFORMED CONSENT

STUDY TITLE: Kinetic comparison of the power development between the hang clean, jump shrug, and high pull

INVESTIGATOR NAME: Timothy Suchomel, Principal Investigator
University of Wisconsin-La Crosse

This form is important. Please read it carefully. This form will tell you everything you need to know about this research study. If you agree to participate in this study, you need to sign this form. Your signature means that you have been informed about the study and understand what potential risks exist. Your signature on this form also means that you want to participate as a subject in this research study.

What is the purpose of this study?

The purpose of this study is to compare the kinetics of the HC, JS, and HP when performed at different relative loads. Power development is determined by assessing the amount of force produced and at what velocity the exercise is performed at.

Your peak force, peak velocity, and peak power will be measured while you complete repetitions of the hang clean, jump shrug, and high pull exercises. Each lift will be assessed on a force platform. This device will measure how hard you push against the ground and how quickly you extend your hip, knee, and ankle joints.

How many people will participate as subjects in this study?

About 20 athletic males will take part in this study.

What will I have to do if I participate in this study?

<u>Day 1</u>:

The first session will be used to collect your demographics (age, height, and weight) and one repetition maximum (1RM) hang clean data. You will be asked to complete a standardized dynamic warm up (warm up that involves movement). You will then rest for 2 minutes before further activity. Following your rest period, you will begin your 1RM hang clean testing. You will first perform 4 warm up sets with loads based on your estimated 1RM hang clean. Your loads during the 1RM testing will be determined by the researchers of this study based on your previous training. Following your warm up sets, you will perform one repetition of the hang clean at an increased load until your maximum load is found. Proper rest periods of 3 minutes in between each maximal attempt will be used to prevent fatigue. After your 1RM load has been determined and a 3-5 minute recovery period, you will be asked to complete 5 repetitions of the jump shrug and high pull exercises at a low to moderate load. This will allow you to become familiar with the exercises that will be used during your final testing sessions. Finally, you will schedule your first testing session.

<u>Days 2, 3, and 4</u>:

Each session will be separated by 2-7 days from the previous session. You will be asked to complete 3 final testing sessions. Each session will require you to perform the same standardized dynamic warm up that you did during Day 1. This will again be followed by 2 minutes of rest. Over the course of the three testing sessions, you will complete 3 repetitions of the hang clean, jump shrug, and high pull exercises at 30, 45, 65, and 80% of your 1RM hang clean load. In other words, you will perform 3 repetitions of each exercise at each load. Because testing conditions will be randomized, you will complete 1 exercise at all of the relative loads during each testing session. You will complete 12 repetitions of exercise each testing session totaling 36 repetitions for the whole study. One minute of rest will be given in between repetitions of each set and 2 minutes of rest will be provided in between each set of exercise and load to prevent fatigue.

How long will I be in the research study?

If you choose to sign the informed consent form, you will be asked to attend one 45-minute familiarization session and three 35-minute sessions with 2-7 days in between all sessions. Each session will take place in Mitchell 101. Upon the completion of your third testing session, you will not be asked for further participation in this study.

Will the results of this study be published?

It is the goal of the researchers to publish the results of this study in a scientific journal and/or present the results of this study at a professional conference. If this study is published or presented, no personal identities will be revealed.

Are there any potential risks associated to participation in this study?

If you choose to participate in this study, no activity will put you at greater than minimal risk. The potential risks may include mild muscle soreness and fatigue. The researchers of this study want to assure you that the necessary steps are being taken to ensure your safety and minimize any potential risk that may exist. You will be provided with rest periods in between activity to minimize the chance of fatigue. In addition, the principal researcher will be certified in both First Aid and as a Certified Strength and Conditioning Specialist to ensure only minimal risk exists during all activities.

Are there any benefits to taking part in this study?

The researchers of this study anticipate no direct benefits to those who participate in this study. However, the knowledge gained from this study will provide information concerning exercise selection and comparisons between the hang clean, jump shrug, and high pull that is lacking in previous and current literature related lower limb power development training. It is the hope of the researchers that the information gained from this study will directly impact the strength and conditioning field and help athletes train and perform at a higher level.

Will my information and data be kept private?

Yes. All of your information and data will be kept on a password protected computer in the locked office of the faculty research advisor, Dr. Glenn Wright. Access to subject data will be limited to the principal investigator, faculty research advisor, and assistant researchers of this study. If this study is published or presented, no personal identities will be revealed.

Am I able to drop out of the study?

Yes. Your participation in this research study is completely voluntary. Full participation is encouraged, but you may withdraw from the study at any time without any consequences or penalties.

Who do I contact if I have any questions regarding this study?

You may contact the principal investigator at any time during the study. The principal investigator, Timothy Suchomel, can be reached by telephone at 608-235-9818 or by e-mail at suchomel.timo@uwlax.edu.

You may also contact the faculty research advisor, Dr. Glenn Wright:
137 Mitchell Hall
University of Wisconsin-La Crosse
La Crosse, WI 54601
(608) 785-8689 – office
wright.glen@uwlax.edu

Finally, questions regarding the protection of human subjects may be addressed to:
irb@uwlax.edu

Signatures:

I have been provided with this informed consent form. I have read it or it has been read to me. I understand the information and have had my questions answered. I agree to participate as a subject in this study.

________ ____

(Date) (Signed and Printed Name of Participant)

________ ____

(Date) (Signed and Printed Name of the Principal Investigator)

APPENDIX B

REVIEW OF LITERATURE

REVIEW OF LITERATURE

It is well established that there is a strong relationship between the ability of an athlete to develop high levels of muscular power and their success in sporting events (1-3, 5-8, 12, 13, 15, 16, 20, 22, 23, 27-30, 32-35, 37, 38). As a result, the primary focus of many strength and conditioning programs is developing muscular power to improve overall performance. It is likely that the ideal stimulus for improving muscular power is training in a way that produces maximal power in sports specific movements. This can be accomplished through proper exercise selection, training at optimal loads, or a combination of both that produce the greatest peak power during training. Therefore, it is essential for the strength and conditioning practitioner to implement the best exercise that maximizes power output in the movement that is being trained. In addition to implementing the ideal exercise that produces the greatest power output, finding the optimal load that produces the greatest power output will allow practitioners to prescribe resistance training programs that will allow athletes to optimally improve their muscular power, thus improving their performance (27).

The most common form of training for lower body muscular power involves the triple extension movement. The explosive triple extension of the hip, knee, and ankle joints is a movement that is regularly performed in any sport that involves variations of jumping, running, or striding. For example, basketball players use the triple extension movement while jumping during a jump shot and rebounding, sprinters during their acceleration phase coming out of the blocks, and baseball pitchers when they are striding towards home plate. Because triple extension is so important to many athletic events, it is important that this movement be trained to develop more explosive movements, thereby improving overall performance.

Power Clean Exercise

Training the triple extension movement and maximal lower limb power output can be established in many ways. One of the most common methods of developing lower limb muscular power involves the use of the power clean exercise and its variations (hang clean, hang jump shrug, hang high pull) (4, 5, 9, 14, 16, 19-24, 27-29, 33-35). By incorporating the explosive triple extension of the hip, knee, and ankle joints during the power clean, this exercise and its variations become highly sports specific. As a result, the high sports specificity of the triple extension movement within the power clean allows for a stronger transfer to athletic performance as compared to more traditional lifts, such as back squat which is not as explosive in nature (13, 33). By implementing the power clean and its variations into training programs, strength and conditioning practitioners train the explosive extension of the hip, knee, and ankle joints (27).

The power clean exercise begins with the lifter standing with their feet flat on the floor shoulder width apart, shins close to the bar, hips lower than the shoulders, and arms fully extended. The back of the lifter should be flat and their shoulders should be over the bar while the hands grasp the bar in an overhand grip. The first pull movement begins when the lifter lifts the bar off the floor with a slow, smooth movement. At this point, the lifter begins to raise their hips and shoulders at the same rate while keeping their arms extended and shoulders over the bar. Once the bar passes the knees, the second pull of the movement begins. The second pull requires the lifter to explosively pull the bar vertically while the hip, knee, and ankle joints completely extend in a well sequenced explosive jumping movement. Furthermore, the lifter shrugs their shoulders and keeps their elbows high which allows them to elevate the bar. "Catching" the weight is the final phase of the power clean exercise. This phase requires the lifter to rapidly rotate their elbows under the bar, while projecting them forward and keeping them high, and catching the bar across their shoulders. Also during this time, the lifter must flex their knees and hips to a semi-squat position to absorb the weight of the bar during the catch phase (13, 14, 16, 19, 23, 35).

A commonly used variation of the power clean exercise in resistance training programs is the hang clean. The primary difference between the two exercises is that the hang clean starts from a standing position as opposed to the power clean that begins by lifting the weight off of the floor. The same explosive triple extension movement of the second pull is required to successfully complete the lift. However, the hang clean begins with the lifter lowering the bar down their thighs until the bar is just above their knees while keeping their knees slightly bent. Additionally, the back of the lifter should be flat and their shoulders should stay in line vertically with the bar. Without pausing with the bar at this point, the lifter explosively performs the second pull movements as described above during the power clean. Like the power clean, the hang clean variation is also considered very technique oriented because it also requires the lifter to perform the catch phase. Because the second pull of Olympic lifts and their variations produce a higher force and power output as compared to the first pull (13, 14, 15, 22), the hang clean variation is commonly used in training, especially when first learning.

Despite being commonly used exercises in training programs used to develop and train lower limb power, the power clean and its hang clean variation are very skill dependent lifts that involve the catch phase (35). The second pull phase, which includes the triple extension movement, is what makes these exercises sports specific (22). However, the complexity of the catch phase and the notion that it has very little relevance to specific movements in sports other than Olympic weightlifting raises the question if these exercises are as functional as they are popular in the strength and conditioning profession. Further, because of its complexity, it is common to teach the catch phase using lighter loads or PVC pipe and increase the load gradually to perfect the catch technique before overloading is accomplished (22). By focusing on the technique of catching the barbell, practitioners delay the focus on the important explosive elements of the lift which may delay any expected training adaptations this exercise is used for, to develop explosive power in the triple extension (14).

Nearly all explosive movements in sports require the athlete to accelerate through the entire motion (22). To improve these movements, athletes should train with sports specific exercises that allow them to accelerate throughout the entire movement without intentionally decelerating at the end of the motion (32). As noted earlier, the catch phase of the power clean and hang clean follows the second pull in the lift where the body is fully extended and the majority of the work has been completed (14, 15). Hori et al. (22) stated that during weightlifting exercises, the upward movement of the bar does not decelerate until extension is complete. Therefore, if a lifter focuses on dipping under the bar and catching the weight across their shoulders and this distracts from fully executing the triple extension movement, it is possible that the bar would begin to decelerate prior to the joints reaching full extension and therefore, the bar may not reach maximum velocity. Furthermore, this would lead to a reduction in maximal power output, thus decreasing the training benefits of the exercise (22).

Jump shrugs and high pulls are Olympic lift variations that combine aspects of the power clean and the starting position of the hang clean. Neither of these exercises requires the lifter to complete the complex catch phase of the power clean. However, both exercises still require the lifter to perform the explosive triple extension movement, which will enable the lifter to train for improved lower limb power.

The jump shrug requires the lifter to start in a standing position and lower the bar down their thighs until the bar is just above their knees, identical to the beginning of the hang clean. Without pausing with the bar at this point, the lifter explosively performs the beginning of the second pull movements, as described above, by jumping and violently shrugging their shoulders (14, 19, 23).

The high pull is another exercise variation that allows the lifter to explosively train the triple extension movement. Similar to the jump shrug, the high pull does not require the lifter to perform the catch phase. The high pull does however require the lifter to perform the entire second pull motion which will include the jump shrug movement and elevating the bar to their chest level (14, 23). Because the lifter does not catch the bar across their shoulders, the lifter only drives their elbows upward after they have explosively extended their hips, knees, and ankles with the bar reaching their chest height (14).

The hang clean, jump shrug, and high pull exercises are variations of the power clean exercise that are typically used in a teaching progression for the power clean, but also serve as exercises to train lower limb power (23, 27). Hang exercises are effective in developing lower limb muscular power because they concentrate on performing the second pull of the exercise, which produces a greater force and power output than the first pull (13, 14, 15, 22). At the end of the second pull, the body is fully extended, the barbell has been elevated above the waist, the barbell has reached maximum velocity, and most importantly, the majority of the mechanical work required to complete the lift has been completed by the lower body (15). Hydock et al. (23) suggested that the pull phase of Olympic lifts should be used more in training to develop lower limb muscular power. Furthermore, by training with movements that concentrate on the "pull" phase, an athlete may be able to train at optimal loads while eliminating the catch phase of the hang clean.

Newton et al. (32) examined the kinematics, kinetics, and muscle activation differences between a traditional bench press performed explosively, where the lifter held onto the barbell during the entire movement, and the ballistic bench throw, where the barbell was projected from the lifter's hands upon completing the bench press movement. Their results indicated that the traditional bench press yielded a reduced velocity, force output, and muscle activation due to the fact that the load must stop at the end of the movement. In contrast, the explosive bench throw displayed that the muscles were active throughout the movement which allowed the load to be accelerated throughout the entire movement. As previously noted, the authors concluded that it would be beneficial to athletes to train with sports specific exercises that allow them to accelerate throughout the entire range of motion without intentionally decelerating at the end of the movement (32). Following the concentric muscle action during the bench throw, the barbell is projected from the lifter's hands. The jump shrug is a ballistic movement that has a take-off phase similar to the release of the barbell from the lifter's hands during the bench throw. The take-off phase indicates that it is likely that the lifter is able to accelerate throughout the entire movement without intentionally decelerating. Thus, the jump shrug is likely to produce a greater force output, velocity, and by extension, power output, than the hang clean because a lifter completing the hang clean may not reach full extension and reach the take-off point.

A pair of studies by Comfort et al. (4, 5) compared the peak ground reaction forces and instantaneous rate of force development between the power clean, hang clean, midthigh power clean (catch phase included), and midthigh clean pull exercises. Their results indicated that both the midthigh power clean and midthigh clean pull exercises produced significantly greater peak ground reaction forces and instantaneous rates of force development than the power clean and hang clean exercises. In their first paper (4), the authors concluded that the combination of greater peak ground reaction forces and instantaneous rate of force development produced by the midthigh clean pull and midthigh power clean exercises would likely yield greater peak power outputs if compared to the power clean and hang clean exercises. Furthermore, the use of the midthigh clean pull and midthigh power clean exercises may be advantageous if the primary training goal is power output (4). While power output was not reported in the first study by Comfort et al. (4), support of their conclusions came in their follow-up paper (5). Their results displayed that both the midthigh power clean and midthigh clean pull exercises produced significantly greater peak power output than the power clean and hang clean exercises. Based on these results, the authors concluded that the most advantageous variations of the power clean exercise are the midthigh variations (5). Despite significant differences between the midthigh variations and the power clean and hang clean exercises, it should be noted that the hang clean exercise and midthigh variations used by Comfort et al. (4, 5), may be performed with a lowering of the barbell (countermovement) to the desired position which would incorporate more stretch-shortening cycle contributions to peak ground reaction force and instantaneous rate of force development.

Based on the arguments presented, which are supported by other researchers (2, 22), it is suggested that due to the difficulties in coaching the highly technical power clean, it may be essential to substitute other less technical exercises to train lower limb muscular power. Furthermore, the ability to produce high vertical ground reaction forces and power during the second pull and the complexity of the catch phase, which may lead to a reduction in force production, suggests that the jump shrug and high pull exercises may be more effective at producing a greater vertical ground reaction forces and power output than a hang clean or power clean variation that requires the catch phase making the jump shrug and high pull more sports specific for athletes that do not compete in the sport of weightlifting. By using the less technical jump shrug and high pull exercises, athletes will be able to effectively train the explosive triple extension movement that is specific in sports while limiting a potentially longer learning period that is typical of the hang clean or power clean variation that includes the catch phase.

Optimal loading

Because many sports require high power output and explosiveness, training at optimal loads that provide the greatest stimulus for improved power output is desired (22, 28, 30, 31). The optimal load used for training maximal power output varies by the nature of the exercise (upper vs. lower body, single vs. multi joint, non-explosive traditional vs. explosive) and the training status and experience of the athlete (28). Research has displayed that a strong correlation between maximal strength and maximal power output exists (2, 31). This indicates a strong need for researchers and strength and conditioning practitioners to find exercises that produce maximal power outputs in sport specific movements.

Previous research has indicated that optimal loads used for training maximal power output range anywhere from 0-80% 1RM depending on the type of exercise (3, 7, 9-13, 27, 29, 30, 34, 36, 38). This wide range of percentages indicates that load specificity for maximal power output may differ for each exercise (25, 31). For example, the ballistic bench throw, jump squat, and back squat exercises all display wide ranges of optimal loads that produce the greatest peak power output (PPO) relative to that exercise. Previous research indicates that the optimal load for ballistic bench throws has been found to be between 30 and 70% 1RM (3, 12, 36). Various research studies that examined the optimal load for the jump squat found that PPO occurred anywhere between 0 and 50% 1RM (3, 7, 9-11, 34, 36). Research that was completed with the back squat exercise determined that the optimal load that produced the greatest PPO occurred between 40 and 56% 1RM (9-11, 38). It is likely that differences in methodology contributed to the wide ranges of optimal loads.

Previous research has displayed that the optimal loads for the above exercises varies. However, there is a stronger agreement among researchers for the optimal loads that produce the highest PPO in Olympic style lifts such as the power clean, hang clean, and snatch exercises. Cormie et al. (9-11) and Kilduff et al. (29) researched Olympic style lifts and determined that PPO output for the power clean and hang clean exercises, respectively, occurred at 80% 1RM. Although most optimal loading studies with Olympic style lifting agree with 80% 1RM, the findings of two studies (6, 27) differ slightly. Comfort et al. (6) determined that the optimal load for the power clean exercise also occurred at 70% 1RM. In addition, Kawamori et al. (27) concluded that the optimal load for the hang clean exercise occurred at 70% 1RM. The recently discussed research displays that a strong agreement exists between researchers that the optimal load for Olympic style lifts occurs between 70 and 80% 1RM (6, 9-11, 27, 29). However, it should be noted that no significant difference existed between the load that maximized PPO and 60-80% 1RM (6) or 50-90% 1RM (9, 27, 29). The general agreement between researchers suggests that the optimal load that will maximize PPO during Olympic style lifts will be much higher when compared to traditional resistance training exercises. Garhammer (13) suggests that this finding is due to the high force production and high velocity movements that are required during Olympic style lifts. By identifying the optimal load for each exercise, resistance training programs can be adapted to allow athletes to train at the load that will optimally improve their muscular power (27).

Power Data Collection Methodology

Several studies have investigated different methods of measuring power output during lower limb weight lifting exercises (10, 11, 17, 18, 20, 21). Of particular interest is what method provides the researcher with the most valid measure of power output. Currently, many different methods are used to quantify power output including 1-linear position transducer (LPT), 1-LPT + MASS, 2-LPTs, a force plate (FP), 1-LPT + FP, and 2-LPTs + FP. Differences in methodology can provide vastly different results and may lead a researcher to interpret results inaccurately. Thus, the comparison of data that uses different methods should be avoided (17, 18).

When examining various methods during dynamic lower body resistance exercises (jump squat, squat, and power clean), Cormie et al. (10) indicated that that the 1-LPT and 2-LPT methods displayed consistently higher power output values during the exercises due to the increased force determined by double differentiation of bar displacement. This finding is in agreement with Hansen et al. (17) who stated that peak force is consistently overestimated when using LPT data. In contrast, the 1-LPT+MASS method consistently underestimated power output during the different exercises because force was determined without including acceleration of the system mass (10). Hori et al. (21) indicated that the 1-LPT method may be used if coaches wanted to evaluate lifting performance because the success of weightlifting depends on the power applied to the barbell instead of the lifter's body mass. However, coaches and researchers should be aware that the 1-LPT method demonstrated the least inter-day peak power consistency when compared to the FP and 1-LPT + FP methods during the jump squat exercise (18).

The previously mentioned methods (1-LPT, 2-LPT, and 1-LPT + MASS) use a process termed double differentiation to calculate acceleration and eventually power. Because double differentiation requires additional calculations, a disadvantage to this method is that small measurement errors in barbell displacement may be magnified (10, 11, 17, 18, 20). A second disadvantage of these methods includes the fact that they only account for forces applied to the barbell and do not consider the acceleration or mass of the lifter (20). If one is interested in measuring the amount of power output by the lifter, these methods may not be practical. Another disadvantage of these methods is that they assume that the displacement of the center of gravity of the system is the same as the displacement of the barbell (20, 21). Hori et al. (20) demonstrated that the methods of 1-LPT + MASS and 1-LPT + FP displayed significant differences between the velocity of the center of gravity of the barbell and that of the system during the jump squat exercise. These differences in velocity resulted in a power output that was different from the FP only method. As a result, the researchers concluded that one cannot assume that the center of gravity of the barbell and that of the system move in parallel during the jump squat exercise. However, it is expected that the center of gravity of the barbell and that of the system will not move in parallel during the hang clean exercise (20, 21). Because the 1-LPT + MASS method assumes that the center of gravity of the barbell and that of the system move in parallel, this method does not provide a valid measurement of power output during Olympic style lifts (21).

The FP method is commonly used to measure power output during lower body exercises. Cormie et al. (10) stated that the FP only method under-represented the velocity of the center of mass as well as power output, especially during the power clean because the bar travels independently of the body. However, because force is obtained by the force platform as ground reaction forces, it does not matter that the center of gravity of the barbell and that of the lifter move in parallel or separately because the lifter's body mass is included into the calculations of velocity and power (21). In addition, the FP only method is a preferred method to measure power output during Olympic style lifts (21). Hori et al. (20) concluded that the FP only method was the most reliable measure of quantifying force, velocity, and power during the hang clean and jump squat exercises. Furthermore, the FP only method will remain a valid measurement unless the exercise starts from the floor or pulling blocks because the FP cannot measure forces that are applied to places other than the plate surface (20, 21). This may become an issue when trying to measure power output during a power clean variation that begins either from the floor or from a standardized starting position height. As a result, researchers using the FP method to quantify power output using a power clean variation should use exercises that start from a hang position at the mid-thigh, knee, or below-knee level (21).

Because many research studies include multiple testing sessions, the inter-day reliability of a measuring device should be examined. Hansen et al. (18) measured inter-day consistency of three different methods of measuring peak power during the jump squat exercise and concluded that the FP only method demonstrated the greatest inter-day consistency while the 1-LPT measurement displayed the least. In addition, the coefficient of variation of the 1-LPT method was more than double than that of the FP method which indicates that the FP only method displays much more precision when measuring peak force (17, 18). Furthermore, the FP and 1-LPT + FP methods are preferred by practitioners because they provide a more accurate measurement of peak power (18).

According to Cormie et al. (10), the most valid measurement of lower limb power output is the 2-LPT + FP method because it provides measurements of both force and multidirectional movement. However, when comparing the hang clean, hang jump shrug, and hang high pull exercises, the 2-LPT + FP may not be the most effective method of measuring the power output of the triple extension movement. As previously mentioned, Cormie et al. (10) stated that the FP only method underestimates velocity and power during the power clean exercise because the bar travels separately from the body. However, methodology in that study does not clarify if the power clean exercise started from the floor. This becomes an issue because if the power clean started from the floor, the FP only method becomes invalid because the mass of the system cannot measure forces that are remote to the force platform (20, 21). In other words, the mass of the entire system (body mass + weight) is not constant throughout the exercise. As a result, it is possible that the values quantified by Cormie et al. (10) may be inaccurate if the power clean exercise started from the floor. Therefore, to quantify and compare the differences between lower limb power output during the hang clean, hang jump shrug, and hang high pull exercises, previous research suggests that the FP only method is the most reliable and logical method for this purpose (17, 18, 20, 21).

Another methodology issue when quantifying lower limb power output exists with the inclusion or exclusion of body mass in power calculations. Cormie et al. (11) examined the influence of body mass on the calculation of power during the jump squat, squat, and power clean exercises. Their results indicated that power output is consistently underestimated through the loading spectrum if body mass is excluded in the power calculations. As a result, the load-power relationship is affected by diminishing power output at lighter loads to a greater extent than heavy loads. Because body mass is part of the system that needs to be accelerated, it is generally included into power output equations as part of the force data. However, Cormie et al. (11) theorized that because the lower legs and feet remain relatively static when the greatest amount of power is generated (just prior to takeoff for the jump squat, concentric phase of squat, and second pull for power clean), the most accurate measurement of power output should exclude the mass of the shanks and feet. However, it should be noted that the theorized method in this study was not significantly different than the method that incorporated the entire body mass.

Summary

It is well documented that a strong relationship exists between the ability of an athlete to develop high levels of muscular power and their success in sporting events (1-3, 5-8, 12, 13, 15, 16, 20, 22, 23, 27-30, 32-35, 37, 38). One of the most common movements in athletics is the triple extension of the hip, knee, and ankle joints. Because the triple extension movement is required in many athletic events, the focus of many strength and conditioning practitioners is the development of lower limb muscular power. By training the triple extension movement, practitioners hope to improve the overall performance of athletes in sports competitions.

The power clean and its variations are commonly used to train lower limb muscular power (4, 5, 9, 14, 16, 19-24, 27-29, 33-35). It is the second pull phase, which includes the triple extension movement, which makes these exercises sports specific (22). However, the power clean is a very skill dependent lift that involves the catch phase (35). The catch phase follows the point at which the body is fully extended and the majority of work has been completed (14, 15). Therefore, if a lifter focuses on dipping under the bar and catching the weight across their shoulders instead of fully executing the triple extension movement, it is possible that the bar would begin to decelerate prior to the joints reaching full extension and therefore, the bar may not reach maximum velocity. Furthermore, this would lead to a reduction in maximal power output (32), thus decreasing the training benefits of the exercise (22). The complexity of the catch phase and the notion that it has very little relevance to specific movements in sports other than Olympic weightlifting, raises the question, are these exercises as functional as they are popular in the strength and conditioning profession?

Nearly all explosive movements in athletics require the athlete to accelerate through the entire motion (22). Thus, the optimal way to train these movements is to train with sports specific exercises that allow athletes to accelerate throughout the entire movement (32). Due to the difficulties in coaching the highly technical power clean, it has been suggested that it may be essential to substitute other less technical exercises to train lower limb muscular power (2, 22). Two power clean variations, the jump shrug and high pull, train the triple extension movement, but also allow the athlete to accelerate throughout the entire motion and eliminate the skill of the catch phase. The maximal power production provided by the jump shrug and high pull may be significantly greater than that of the power clean because they do not require the non-sports specific movement of the catch, thus making these exercises more beneficial for sports specific training. If the jump shrug and high pull exercises produce similar or more power during the triple extension movement than the power clean exercise, strength and conditioning practitioners could consider implementing the jump shrug and high pull exercises more frequently into their written training programs.

Much research has sought to identify the optimal load that produces the greatest power output during the power clean and its variations (6, 9-11, 27, 29). Comfort et al. (6) concluded that the peak power output during the power clean occurs at 70% 1-repetition maximum (1RM), while Cormie et al. (9-11) determined that the peak power output during the power clean occurs at 80% 1RM. However, it should be noted that the load that produced the greatest peak power output was not significantly different than loads between 60 and 80% 1RM (6) or between 50 and 90% 1RM (9). In addition, Kawamori et al. (27) found that the peak power output during the hang clean exercise occurred at 70% 1RM. Research by Kilduff et al. (29) differed slightly with peak power output occurring at 80% 1RM for the hang clean exercise. However, it should be noted that both studies (27, 29) did not display any significant differences between the load that maximized peak power output and loads as low as 50% 1RM and as high as 90% 1RM.

It is likely that the ideal stimulus for improving muscular power is training in a way that produces maximal power in sports specific movements. Therefore, it is essential that the strength and conditioning practitioner selects an exercise that maximizes power output in the movement that is being trained. Furthermore, by identifying and training at the ideal load for that specific exercise, athletes will be able to optimally improve their muscular power and by extension, their overall performance (27). Therefore, the purpose of this study is to compare the kinetics of the HC, JS, and HP when performed at different relative loads.

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