Short Communication

Comparison of peak power output during exercises with similar lower-limb kinematics

Paul Comfort, Peter D. Mundy, Philip Graham-Smith, Paul A. Jones, Laura C. Smith, Jason P. Lake

Objectives: The aim of this investigation was to compare peak power between the mid-thigh power clean, squat jump and push press.

Design and Methods: Eleven recreationally trained men (age 22.2 ± 3.5 yrs; height 178.6 ± 8.5 cm; body mass 88.7 ± 13.5 kg) performed one set of three repetitions of the mid-thigh power clean, squat jump and push press, with 50, 60 and 70% of respective 1RM, while standing on two force platforms. The effect of load and lift on peak power was analyzed with two-way analysis of variance.

Results: Peak power was highest during mid-thigh power clean (4739.2 ± 1015.8 W), but was not significantly higher than the squat jump (4430.4 ± 1140.3 W, Cohen's $d = 0.29$) and push press (4071.1 ± 1552.3 W, Cohen's $d = 0.51$) performed at equivalent intensities. Similarly, the load effect on peak power was non-significant and trivial (Cohen's $d < 0.35$).

Conclusions: The findings of this study show that when training to maximize peak power output the mid-thigh power clean, squat jump and push press performed at 50-70% of 1RM could be incorporated interchangeably without any detriment to peak power output.

(*Journal of Trainology* 2016;5:1-5)

Key words: Peak force ■ Power ■ Performance ■ Kinetics

INTRODUCTION

A number of studies have investigated the optimal load required to achieve peak power during a variety of exercises, including the squat jump[1-4] power clean[2, 5] hang power clean[6-8], mid-thigh clean pull[9] and jump shrug.[10] Inclusion of these exercises in strength and conditioning programs can improve athletic performance by imitating sport-specific movements such as rapid force production via explosive triple extension of the ankles, knees and hips.[4, 11] With maximum performance during the squat[12, 13] and power clean[14] and jump power[12, 15] are related to sprint performance.

Much of the research regarding power characteristics during performances of the clean and its variations have focused on the load that achieves the greatest peak power, revealing that peak power output occurs at different loads for different exercises. Peak power during the power clean has been reported to occur at around 80% 1RM[2, 16] while peak power occurs around 70% 1RM during the hang power clean[7, 17] and at 60% 1RM during the mid-thigh clean pull[18]. However, more recently Comfort et al.[9, 19] reported that mid-thigh clean pull peak power and peak bar velocity was achieved between 40-60% 1RM, while peak vertical ground reaction force (vGRF) and peak rate of force development (RFD) occurred between 120-140% of power clean 1RM. In addition, Suchomel et al.[17] observed that peak power output during jump shrug (similar to the mid-thigh clean pull) occurred with 30% 1RM and was significantly greater than hang power clean and hang high pull peak power.

There is limited evidence regarding to which variation of the clean maximizes power, although recently presented data indicates that the mid-thigh power clean and mid-thigh clean pull may maximize power,[20] and that it is maximized with loads of around 40-60% 1RM power clean.[9, 19] Similar findings have been reported for the jump shrug, compared to the hang high pull and hang power clean.[17] Such findings are not surprising as previous researchers identified that the second pull phase of the power clean results in the greatest vGRF compared to other phases.[21-23] Additionally, Garhammer[24-26] previously reported that peak power occurs during the second pull of the Olympic lifts, although these studies reported barbell power rather than system power.

Strength and conditioning coaches use a variety of different exercises when training to enhance power, including jumping exercises (both with and without external load), overhead lifts (e.g. push press) and derivatives of the Olympic lifts (e.g. mid-thigh power clean). It is reasonable to assume that because the drive phase of the squat jump and push press exercise is underpinned by rapid extension of the ankles, knees and hips, that lower-body kinematics are similar to those underpinning the second pull of the mid-thigh power clean. This hypothesis is tentatively supported by data published by Garhammer[25, 26, 28] about similarities between clean second pull and jerk propul-

Received August 9, 2015; accepted March 1, 2016

From the Human Performance Laboratory, Directorate of Sport, Exercise and Physiotherapy, University of Salford, Salford, Greater Manchester, United Kingdom (P.C., P.A.J., L.C.S.), Department of Applied Science and Health, Coventry University, Coventry, United Kingdom (P.D.M.), Department of Sport and Exercise Sciences, University of Chichester, Chichester, United Kingdom (P.D.M., J.P.L.), and Aspire Academy for Sports Excellence, Dohar, Qatar (P.G.S.)

Communicated by Takashi Abe, PhD

Correspondence to Dr. Paul Comfort, Human Performance Laboratory, Directorate of Sport, Exercise and Physiotherapy, University of Salford, Salford, Greater Manchester, UK. Email: p.comfort@salford.ac.uk

sion phase power outputs. Only one direct comparison of the peak power achieved during the mid-thing power clean, squat jump and push press has been reported. However, a fixed load of 60% of power clean 1RM was used and exercise did not significantly effect peak force, peak RFD or peak power,[29] further research is required to determine the effect of commonly used loads relative to the 1RM for each exercise, on peak power. Additionally, such exercises are performed across a variety of loads, to ensure that the force-velocity and load-velocity continuum are appropriately trained and developed.[27] Interestingly, Lake et al.[30] reported that peak power was similar between the push press and squat jump when performed between 10-90% of respective exercise 1RM.

Comparison of peak power during the mid-thigh power clean, squat jump and push press may assist strength and conditioning coaches make more informed decisions when selecting such exercises for power development programs. Therefore, the aim of this study was to compare peak power output during the mid-thigh power clean, squat jump and push press with loads equivalent to 50, 60 and 70% of 1RM for each exercise.

METHODS

This study employed a within subjects repeated measures research design, whereby peak power was determined during the mid-thigh power clean, squat jump and push press at loads of 50, 60 and 70% of each exercises individual 1RM, in a randomized counterbalanced order. Force-time data were recorded from two force plates during performance of the three exercises, and the effect of load and exercise was studied.

Participants

Based on an *a priori* power analysis (effect size f = 0.4; α = 0.05; β = 0.80), eleven healthy, male amateur team sport athletes (age: 22.2 ± 3.5 yrs; height: 178.6 ± 8.5 cm; body mass: 88.7 ± 13.5 kg; push press 1RM: 85.4 ± 8.3 kg; power clean 1RM: 93.7 ± 6.8 kg; back squat 1RM: 142.5 ± 12.3 kg), with ≥ 2 years experience with each lift, participated in this study. Participants had previously habituated with the testing protocol during technique sessions. The investigation was approved by the Institutional Ethics Committee and all participants provided informed consent prior to participation. The study conformed to the principles of the World Medical Association's Declaration of Helsinki.

Procedures

Participants were asked to attend the laboratory in a fed and hydrated state, and to maintain a standardized food and fluid intake on each of the three days of testing. Repeated testing took place 3-4 days apart, at a similar time of day, with subjects asked to abstain from strenuous exercise for the 48 hours prior to testing. For the one 1RM assessments this equated to 6 sessions (2 × per exercise for each of the 3 exercises), with a single session for the trials to determine any differences between loads and exercises.

One Repetition Maximum Testing

One repetition maximums were conducted on two separate occasions, individually for each exercise, 3-4 days apart to establish between session reliability, which was very high intraclass correlation coefficient (ICC) = 0.988 (squat), 0.978, (power clean), and 0.910 (push press). All 1RM were recorded following the standardized NSCA protocol.[31]

Power Testing

Prior to testing all subjects performed a standardized dynamic warm up, including performance of each lift (3 repetitions, 2 sets) using a standardize load (40% 1RM) (WerkSan Olympic bar and weights, New Jersey, USA). Participants were then randomly assigned to perform one cluster set of three repetitions (30 second rest between repetitions to minimize fatigue) of each exercise, at each load in a randomized, counterbalanced order. All lifts were performed using a 50, 60 and 70% of previously determined respective exercise 1RM. Loads were chosen to reflect the range of loads which have most commonly been reported to elicit peak power during such exercise, but ensure that the volume of exercise would not induce excessive fatigue. Five minutes rest was provided between different loads and lifts to ensure sufficient replenishment of energy substrates. The mid-thigh power clean was performed with the bar held at mid-thigh, not resting on blocks, to ensure that the load was already applied to the subject and therefore the force plates, as would be the case for the squat jump and push press. The squat jump and push press were performed using a standard technique[30], with no attempts made to control the depth of the countermovement.

Each subject performed all lifts on two floor mounted force plates (600 mm × 900 mm) (Advanced Medical Technologies Inc., Newton, Massachusetts, USA), sampling at 1000 Hz. During the lifts the subjects were instructed to stand with one foot on each force plate. The vGRF from each force plate was acquired using Qualisys Track Manager (Version 2.7, Qualisys AB, Gothenburg, Sweden) and exported to MS Excel where left and right side data summed for further analysis. Velocity of the centre of gravity (COG) of the system (barbell + body mass) was calculated from vGRF based on the relationship between impulse and momentum in which impulse is equal to the changes in momentum (forward dynamics approach).[16, 32-34] Power was then calculated by multiplying the velocity of the system COG by vGRF at each time point.[16, 32-34] Peak power was identified as the highest instantaneous power, and was recorded for further analysis.

Statistical Analyses

Reproducibility of the peak power output for each exercise and load was assessed via ICC's. A two-way analysis of variance (ANOVA) (3 × 3) and Bonferroni post-hoc analysis was conducted using SPSS (Version 20.0) to determine if there was a significant difference in peak power between lifts and between loads. Prior to analysis, data were checked for normality using a Shapiro-Wilk test. Effect sizes were determined using the Cohen *d* method, and interpreted based on the recommendations of Rhea[35] who defines < 0.35, 0.35-0.80, 0.80-

1.5 and > 1.5 as trivial, small, moderate and large respectively. An *a priori* alpha level was set to $p < 0.05$.

RESULTS

All ICC's demonstrated a high level of reliability for peak power output (≥ 0.97, 0.99, 0.99) for the mid-thigh power clean, squat jump and push press, respectively.

The mid-thigh power clean resulted in the highest peak power (4739.2 ± 1015.8 W), although when compared to the squat jump (4430.4 ± 1140.3 W, Cohen's d = 0.29) and push press (4071.1 ± 1552.3 W, Cohen's d = 0.51), these were not significantly different (Figure 1).

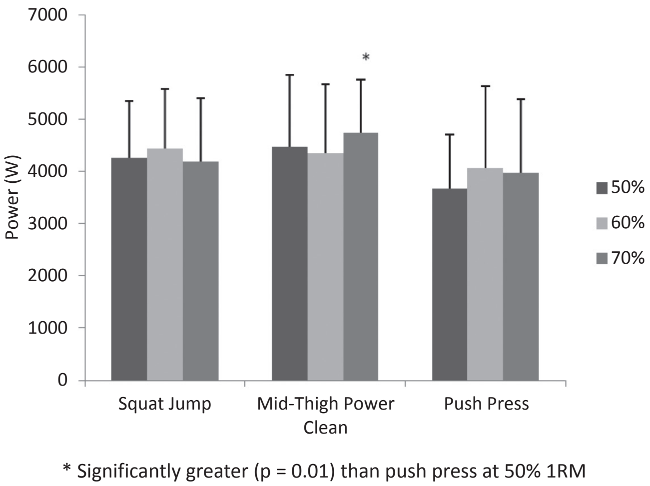

Figure 1 Comparison of peak power across loads and exercises

Load did not significantly effect squat jump (50% 1RM 4257.5 ± 1081.1 W, 60% 1RM 4430.4 ± 1140.3 W, 70% 1RM 4195.4 ± 1212.0 W, Cohen's $d \leq 0.20$), mid-thigh power clean (50% 1RM 4479.3 ± 1357.2 W, 60% 1RM 4352.5 ± 1319.6 W, 70% 1RM 4739.2 ± 1015.8 W, Cohen's $d \leq 0.33$) and push press (50% 1RM, 3676.0 ± 1020.3 W, 60% 1RM 4071.1 ± 1552.3 W, 70% 1RM 3967.2 ± 1416.0 W, Cohen's $d \leq 0.30$) peak power. Bonferonni post hoc-analysis revealed a load by exercise interaction; mid-thigh power clean peak power with 70% 1RM (4739.2 ± 1015.8 W) was significantly greater than push press peak power with 50% 1RM (3676.0 ± 1020.3 W) ($p = 0.01$, Cohen's d = 1.04). There were no other significant effects (Figure 1).

DISCUSSION

The results of this study demonstrate that there were no significant exercise or load effects on mid-thigh power clean, squat jump or push press peak power with the same relative loads. There was, however, an exercise by load interaction whereby peak power during the mid-thigh power clean with 70% 1RM (4739.2 ± 1015.8 W) was significantly and moderately ($p = 0.01$, Cohen's d = 1.04) greater than push press peak power with 50% 1RM (3676.0 ± 1020.3 W), although this was not significantly greater ($p > 0.05$) than any other exercise at any load.

The similarity in exercise peak power may be explained by the fact that the lower-limb kinematics are similar between lifts, with similarities in power output reported in both the clean and the jerk in competitive weightlifters (Garhammer, 1980, 1985, 1991). Comfort et al.[29] also reported no difference in mid-thigh power clean, squat jump and push press peak power, force or RFD with a standardized load of 60 % 1RM power clean. Further, the lack of load effect for each exercise is similar to previously reported findings that peak power occurs across a spectrum of loads. Comfort et al.[5] reported no significant difference in peak power output between 60, 70 and 80% of power clean 1RM, while Kilduff et al.[8] reported no significant difference between loads of 50, 60, 70, 80 or 90% of power clean 1RM during the hang power clean. Similarly, when comparing the squat jump and push press at similar loads, Lake et al.[30] found no difference in peak power.

The optimal load to achieve peak power during mid-thigh clean pulls has been shown to be 40-60% of power clean 1RM[9, 18, 19], and therefore may partly explain why the mid-thigh power clean resulted in the greatest peak power. However, when comparing mean values in this study there is actually a slight decrease in peak power at 60% 1RM, although this was not significant ($p > 0.05$). In contrast, optimal loading for squat jump has been established at lower loads (body mass, with no external load)[1, 3, 36, 37], whereas optimal loading for the push press has been established at higher loads (75.3 ± 16.4).[30] As such, it is possible that the optimal load may be outside of the brief range of loads used in this investigation. Clearly, it was not possible to assess power output during each exercise from loads of 0-90%, due to the resultant volume, and the fact that the mid-thigh power clean and push press would not be performed unloaded.

It is recommended that further research determine whether these findings are similar across a larger spectrum of loads (e.g. 30-90% 1RM at 20% increments). Additionally, comparison of propulsion phase kinetics during the push press, push jerk and split jerk would be informative to strength and conditioning coaches and sports scientists, to aid in the selection of exercises. However, the results of this study may help strength and conditioning coaches make more informed choices about which resistance training exercise they chose for the lower-body power development part of athlete strength and conditioning programs. For example, while there are no significant differences between the peak power achieved during these exercises, they each offer a relatively unique training variation. While the squat jump focuses on the purest form of lower-body jump power development, it can also include a potentially high landing impact force[33]. If this is the case the coach may prescribe variations of the Olympic lifts. Research has indicated that while the power clean can be used to effectively develop lower-body power, the catch element may not be necessary, or indeed, beneficial[38]. If this is the case, the coach has the option of prescribing either the squat jump or push press; as researchers have shown that there is no difference between the peak power achieved during these exercises[30]. If the coach is concerned about the impact forces associated with squat jump landing, then the push press may make a suitable alternative.

However, if the coach is also concerned about the overhead element of the push press, the coach still has the option of prescribing a variation of the clean exercise while eliminating the catch exercise[39].

With the above in mind, it should also be remembered that while these exercises focus on the lower-body, their technical requirement may alter the emphasis that is placed on different lower-body joints and muscle groups. For example, as load increases during the squat jump the hips may flex more under the load, placing greater emphasis on hip extension. Conversely, variations of the clean tend to be more hip dominant than the squat jump. Finally, the push press remains relatively knee dominant across progressive loading because of the need to keep the barbell on a solid rack on the anterior deltoids in order to efficiently impart impulse to it. Therefore, strength and conditioning coaches should consider this when selecting exercises for lower-body power development.

CONCLUSION

The results of this study show that when training to develop peak power the mid-thigh power clean, push press and squat jump, performed with 50-70% of their respective 1RM, could be programmed interchangeably without any detrimental effect on peak power output. It is suggested that strength and conditioning coaches select either the mid-thigh power clean, squat jump or push press to include in power mesocycles after considering the subtle differences in the movement patterns of each exercise. Alternating between these exercises over successive mesocycles to address different movement patterns may aid in the reduction of repetitive strain and aid motivation by introducing variety into the training regimen.

Acknowledgements: The authors would like to thank all individuals who participated in this investigation

No funding was received in support of this investigation, and the authors have no conflict of interest.

REFERENCES

1. Cormie P, McBride JM, McCaulley GO. Power-time, force-time, and velocity-time curve analysis during the jump squat: impact of load. *J Appl Biomech*. May 2008; 24: 112-120.
2. Cormie P, McCaulley GO, Triplett NT, McBride JM. Optimal loading for maximal power output during lower-body resistance exercises. *Med Sci Sports Exerc* 2007; 39: 340-349.
3. Bevan HR, Bunce PJ, Owen NJ, et al. Optimal loading for the development of peak power output in professional rugby players. *J Strength Cond Res* 2010; 24: 43-47.
4. Stone MH, O'Bryant HS, McCoy L, Coglianese R, Lehmkuhl M, Schilling B. Power and Maximum Strength Relationships During Performance of Dynamic and Static Weighted Jumps. *J Strength Cond Res* 2003; 17: 140-147.
5. Comfort P, Fletcher C, McMahon JJ. Determination of optimal load during the power clean in collegiate athletes. *J Strength Cond Res* 2012; 26: 2962-2969.
6. Suchomel TJ, Beckham GK, Wright GA. The impact of load on lower body performance variables during the hang power clean. *Sports Biomech* 2014; 13: 87-95.
7. Kawamori N, Crum AJ, Blumert PA, et al. Influence of Different Relative Intensities on Power Output During the Hang Power Clean: Identification of the Optimal Load. *J Strength Cond Res* 2005; 19: 698-708.
8. Kilduff LP, Bevan H, Owen N, et al. Optimal loading for peak power output during the hang power clean in professional rugby players. *Int J Sports Physiol Perform* 2007; 2: 260-269.
9. Comfort P, Udall R, Jones P. The affect of loading on kinematic and kinetic variables during the mid-thigh clean pull. *J Strength Cond Res* 2012; 26: 1208-1214.
10. Suchomel TJ, Beckham GK, Wright GA. Lower body kinetics during the jump shrug: impact of load. *J Trainol* 2013; 2: 19-22.
11. Stone MH, Sanborn KIM, O'Bryant HS, et al. Maximum Strength-Power-Performance Relationships in Collegiate Throwers. *J Strength Cond Res* 2003; 17: 739-745.
12. Harris NK, Cronin JB, Hopkins WG, Hansen KT. Relationship between sprint times and the strength/power outputs of a machine squat jump. *J Strength Cond Res* 2008; 22:691 -698.
13. McBride JM, Blow D, Kirby TJ, Haines TL, Dayne AM, Triplett NT. Relationship between maximal squat strength and five, ten, and forty yard sprint times. *J Strength Cond Res* 2009; 23: 1633-1636.
14. Hori N, Newton RU, Andrews WA, Kawamori N, McGuigan MR, Nosaka K. Does Performance of Hang Power Clean Differentiate Performance of Jumping, Sprinting, and Changing of Direction? *J Strength Cond Res* 2008; 22: 412-418.
15. Sleivert G, Taingahue M. The relationship between maximal jump-squat power and sprint acceleration in athletes. *Eur J Appl Physiol* 2004; 91: 46-52.
16. Cormie P, McBride JM, McCaulley GO. Validation of power measurement techniques in dynamic lower body resistance exercises. *J Appl Biomech* 2007; 23: 103-118.
17. Suchomel TJ, Wright GA, Kernozek TW, Kline DE. Kinetic Comparison of the Power Development Between Power Clean Variations. *J Strength Cond Res* 2014; 28: 350-360.
18. Kawamori N, Rossi SJ, Justice BD, et al. Peak Force and Rate of Force Development During Isometric and Dynamic Mid-Thigh Clean Pulls Performed At Various Intensities. *J Strength Cond Res* 2006; 20: 483-491.
19. Comfort P, Jones PA, Udall R. The effect of load and sex on kinematic and kinetic variables during the mid-thigh clean pull. *Sports Biomech* 2015; 14: 139-156.
20. Comfort P, Graham-Smith P, Allen M. Kinetic comparisons during variations of the Power Clean. *J Strength Cond Res* 2011; 25: 3269-3273.
21. Enoka RM. The pull in olympic weightlifting. *Med Sci Sports* 1979; 11: 131-137.
22. Hakkinen K, Kauhanen H, Komi PV. Biomechanical changes in the Olympic weightlifting technique of the snatch and the clean & jerk from submaximal to maximal loads. *Scand J Sports Sci* 1984; 6: 57-66.
23. Souza AL, Shimada SD, Koontz A. Ground reaction forces during the power clean. *J Strength Cond Res* 2002; 16: 423-427.
24. Garhammer J. Energy flow during Olympic weight lifting. *Med Sci Sports Exerc*. 1982; 14: 353-360.
25. Garhammer J. Power production by Olympic weightlifters. *Med Sci Sports Exerc* 1980; 12: 54-60.
26. Garhammer J. A comparison of maximal power outputs between elite male and female weightlifters in competition. *Int J Sports Biomech* 1991; 3: 3-11.
27. Haff GG, Nimphius S. Training Principles for Power. *Strength Cond J* 2012; 34: 2-12
28. Garhammer J. Biomechanical profiles of Olympic weightlifters. *Int J Sports Biomech* 1985; 1: 122-130.
29. Comfort P, Mather D, Graham-Smith P. No differences in kinetics between the squat jump, push press and mid-thigh power clean. *J Athl Enhancement* 2013; 2(6).
30. Lake JP, Mundy PD, Comfort P. Power and impulse applied during push press exercise. *J Strength Cond Res* 2014; 28: 2552-2559.
31. Baechle TR, Earle RW, Wathen D. Resistance Training. In: Baechle TR, Earle, R. W, ed. *Essentials of Strength Training and Conditioning*. Champaign, Illinois: Human Kinetics; 2008: 381-412.

32. Cormie P, McBride JM, McCaulley GO. The influence of body mass on calculation of power during lower-body resistance exercises. *J Strength Cond Res* 2007; 21: 1042-1049.
33. Hori N, Newton RU, Andrews WA, Kawamori N, McGuigan MR, Nosaka K. Comparison of Four Different Methods To Measure Power Output During the Hang Power Clean and the Weighted Jump Squat. *J Strength Cond Res* 2007; 21: 314-320.
34. Lake JP, Lauder MA, Smith NA. Barbell Kinematics Should Not Be Used to Estimate Power Output Applied to the Barbell-and-Body System Center of Mass During Lower-Body Resistance Exercise. *J Strength Cond Res* 2012; 26: 1302-1307
35. Rhea MR. Determining the Magnitude of Treatment Effects in Strength Training Research Through the Use of the Effect Size. *J Strength Cond Res* 2004; 18: 918-920.
36. Cormie P, Deane R, McBride JM. Methodological concerns for determining power output in the jump squat. *J Strength Cond Res* 2007; 21: 424-430.
37. Thomasson ML, Comfort P. Occurrence of fatigue during sets of squat jumps performed at a variety of loads. *J Strength Cond Res* 2012; 26: 677-683.
38. Suchomel T, Comfort P, Stone M. Weightlifting Pulling Derivatives: Rationale for Implementation and Application. *Sports Med* 2015; 45: 823-839.
39. Green BS, Blake C, Caulfield BM. A valid field test protocol of linear speed and agility in rugby union. *J Strength Cond Res* 2011; 25: 1256-1262.