9-2021

Comparing Biomechanical Time Series Data During the Hang-Power Clean and Jump Shrug

Kristof Kipp
Marquette University, kristof.kipp@marquette.edu

Paul Comfort
Salford University

Timothy J. Suchomel
Carroll University

Journal of Strength and Conditioning Research, Vol. 35, No. 9 (September 2021): 2389-2396. DOI.

Comparing Biomechanical Time Series Data During the Hang-Power Clean and Jump Shrug

Kristof Kipp
Department of Physical Therapy, Program in Exercise Science, Marquette University, Milwaukee, Wisconsin
Paul Comfort
School of Health & Society, Salford University, Salford, United Kingdom
Department of Human Movement Sciences, Carroll University, Waukesha, Wisconsin
Timothy J. Suchomel
Department of Human Movement Sciences, Carroll University, Waukesha, Wisconsin

Abstract

Kipp, K, Comfort, P, and Suchomel, TJ. Comparing biomechanical time series data during the hang-power clean and jump shrug. *J Strength Cond Res* 35(9): 2389–2396, 2021—The purpose of this study was to investigate differences in the force-, velocity-, displacement-, and power-time curves during the hang-power clean (HPC) and the jump shrug (JS). To this end, 15 male lacrosse players were recruited from a National Collegiate Athletic Association Division-I team, and performed one set of 3 repetitions of the HPC and JS at 70% of their HPC 1 repetition maximum (1RM HPC). Two in-ground force plates were used to measure the vertical ground reaction force (GRF) and calculate the barbell-lifter system mechanics during each exercise. The time series data were normalized to 100% of the movement phase, which included the initial countermovement and extension phases, and analyzed with curve analysis and statistical parametric mapping (SPM). The SPM procedure highlighted significant differences in the force-time curves of the HPC and JS between 85 and 100% of the movement phase. Likewise, the SPM procedure highlighted significant differences in the velocity- and power-time curve of the HPC and JS between 90 and 100% of the movement phase. For all comparisons, performance of the JS was associated with greater magnitudes of the mechanical outputs. Although results from the curve analysis showed significant differences during other periods of the movement phase, these differences likely reflect statistical issues related to the inappropriate analysis of time series data. Nonetheless, these results collectively indicate that when compared with the HPC, execution of the JS is characterized by greater GRF and barbell-lifter system velocity and power outputs during the final 10% of the movement phase.

Keywords:

biomechanics; weightlifting derivatives; resistance training; statistical parametric mapping

Introduction

Weightlifting exercises are commonly used as parts of resistance training programs that aim to improve strength, speed, and power performance of the lower body ([8,11,16,17]). The frequent application of these exercises in resistance training programs is attributed to the biomechanical similarities of weightlifting exercises to other athletic movements that require rapid triple extension of the lower-extremity joints ([7,8,11,17]). Moreover, data from training studies suggest that weightlifting exercises provide a better training stimulus than traditional resistance training, jump training, or kettlebell training ([6,12,22]).

Recent research has focused on weightlifting derivatives, such as the hang-power clean (HPC) and the jump shrug (JS) ([1,2,10,20]). Although both exercises share mechanical similarities, the most notable differences are that the JS emphasizes a more rapid extension of the lower-extremity joints associated with jumping as high as possible ([21]), does not include a catch phase ([16]), and may be the easier exercise to teach and implement ([16]). Research comparing the biomechanics of the JS and HPC indicates that the JS results in greater peak barbell-lifter system velocity, force, and power ([20]). Although these results provide important information about the peak mechanical outputs of the lifter-barbell system, they only offer information about differences at one point in time. Moreover, given that typical mechanical peak values commonly occur during the concentric movement phase (e.g., peak ground reaction force [GRF] or power), these analyses often neglect parameters from the eccentric movement phase. To address these limitations, some researchers have used curve analyses to examine entire force-time or power-time curves and then compare different resistance training exercises, intensities, or adaptations ([4,5,18,19]). Curve analysis essentially uses a continuous band of 95% confidence intervals, derived from standard probability distributions, to make discrete pair-wise comparisons of point data ([4,5,18,19]). Recent research, however, suggests that applying probability distributions for discrete point (i.e., 0-dimensional) data to continuous curve or time series data (i.e., 1-dimensional) is not appropriate because the latter exhibits its own unique probability distributions ([14,15]). Statistical parametric mapping (SPM) uses random-field theory to construct probability distributions based on continuous curve or time series data ([13]). Statistical parametric mapping has thus been suggested to be a better alternative for the analysis of time series data than curve analysis ([13–15]).

Given that previous research on differences in force- and power-time curves between the HPC and JS used curve analysis and showed greater mechanical outputs during the latter exercise ([18,19]), it seems appropriate to investigate whether earlier-reported differences still exist if SPM was used instead of curve analysis. This comparison is especially relevant because recent research suggests little difference in training effects between programs that use either power clean catching derivatives or pulling derivatives ([3]). Given the aforementioned limitations of curve analysis, earlier findings may thus reflect type I statistical errors rather than actual differences in biomechanical time series data ([15]). In addition, although previous studies have investigated only the differences in force- and power-time curves during weightlifting derivatives ([18,19]), none have investigated differences in the velocity- or position-time curves during the HPC or JS. However, examining barbell-lifter velocity- or displacement-time curves during these exercises would provide more holistic and mechanistic insights into any biomechanical and technical differences between the HPC or JS. For example, if force-time curves do not differ between the 2 exercises, greater displacements of the barbell-lifter system may highlight a greater mechanical demand from a work-energy perspective. Conversely, similar barbell-lifter system displacements in the presence of greater GRF may indicate differences in vertical stiffness between the 2 exercises. The purpose of this study was to investigate differences in the force-, velocity-, displacement-, and power-time curves during the HPC and JS. In particular, comparisons between biomechanical time series data were made with curve analysis and SPM. Based on the results of prior research ([18,19]), we hypothesized that the JS would be associated with greater force and power outputs compared to the HPC.

Methods

Experimental Approach to the Problem

To examine the differences in force-, velocity-, displacement-, and power-time curves during the HPC and the JS, we used SPM procedures and curve analysis methods. The dependent variables were therefore the GRF and barbell-lifter velocity, displacement, and power time series data throughout the entire movement phase of both exercises. Given that it is difficult to physically exert maximum force and power (i.e., maximize effort) and still effectively catch the barbell during the HPC with lighter weights, we chose to use loads equivalent to 70% of 1 repetition maximum (1RM) of HPC as a basis for comparing the mechanical outputs. The HPC and JS exercises were treated as a repeated measure as part of the study's within-subject study design.

Subjects

Fifteen male, National Collegiate Athletic Association Division-1 lacrosse players (mean ± *SD*; age: 20.1 ± 1.2 years; height: 1.78 ± 0.07 m; body mass: 80.4 ± 8.1 kg; 1RM HPC: 100.4 ± 8.1 kg; relative 1RM HPC: 1.25 ± 0.13 $kg \cdot kg^{-1}$) participated in this study. All players participated in a yearly training program that included weightlifting exercises, such as the HPC. The study was approved by Marquette University's Institutional Review Board, and all players provided written informed consent before the start of the testing protocol.

Procedures

Testing Protocol

Subjects performed a general warm-up that consisted of light calisthenics and different types of vertical jumps. After the general warm-up, subjects proceeded to a specific warm-up that consisted of 2 sets of 3 repetitions of the HPC at 30 and 50% of 1RM of HPC 1RM, which was based off of results from 1RM testing performed a week before the current study. The 1RM testing protocol was supervised by the University's strength and conditioning staff, and followed similar procedures as described by Winchester et al. ([23]). Subjects then started with either the HPC or JS, and performed one work set of 3 repetitions each at 30, 50, and 70% of 1RM HPC—the loads that these percentages equated to were used for both lifts. The lift that subjects started with (i.e., HPC or JS) was counterbalanced, and the order of work sets was randomized (e.g., 70, 30, 50%). After completing all work sets for one lift, subjects then switched to perform the other exercise, and the same randomization of loads was used for the HPC and JS. All sets were performed as cluster sets with 20 seconds of rest between each repetition and approximately 90 seconds of rest between each set. Subjects were instructed to perform each exercise as they would during their regular strength and conditioning sessions with the University's strength coaches. In general, the technique used by subjects consisted of lowering the barbell to above the knee and performing the lowering and subsequent pulling as rapidly as possible.

Data Collection and Processing

Two force plates (AMTI, Watertown, MA) were used to collect GRF data at 1,000 Hz. Ground reaction force data were filtered with a fourth-order low-pass Butterworth filter at 15 Hz. The filtered GRF data in the vertical direction were summed into a single vector and normalized to the mass of the barbell-lifter system. The normalized GRF data were used to calculate barbell-lifter system velocity, displacement, and power. Specifically, numerical integration with the trapezoidal rule was used to calculate barbell-lifter system velocity and displacement from the vertical GRF data after dividing by the total mass of the barbell-lifter system ([9]). Time series data were time-normalized to 101 data points. The time-normalized thus represented 100% of the movement phase, which was defined as the phase from that began with the initial countermovement and ended with the final triple extension of the lower extremities. More specifically, onset of movement was computationally defined as the point when the GRF fell below 95% of system weight, and termination of movement was defined as the point when the GRF fell below 10 N. Three-trial ensemble averages were created for all biomechanical variables. Again, as explained in the approach to the problem section, for the purposes of this study, only the data from the 70% condition were used for statistical analysis.

Statistical Analyses

Although data were collected at 30, 50, and 70% loads, only data from the 70% condition were used for analysis. This decision was motivated by the fact that it is difficult to exert maximal physical force and power and still effectively catch the barbell in the HPC at lighter loads (i.e., 30 and 50%). Therefore, GRF and velocity-, displacement-, and power-time series data at the 70% loads were compared with curve analysis and SPM. For the curve analysis, 95% confidence intervals were constructed and used to make direct pair-wise comparisons at each time point along the curve. For the SPM procedure, significance thresholds were constructed based on random-field theory and used to test time differences in the series data ([13–15]). The SPM procedure used a function similar to a repeated-measures analysis of variance to compare time series data from the 2 exercises. The significance levels for comparing time series data were set to alpha levels of 0.05.

Results

Force-Time Data

The curve analysis indicated significant differences between the vertical GRF of the HPC and JS between ∼46 and 50% (between $0.029 < p < 0.037$) and between ∼82 and 100% of the movement phase (all $p < 0.001$) (Figure 1A). Post hoc analysis showed that the vertical GRF of the JS were lower than the HPC during the first interval, but greater during the latter interval.

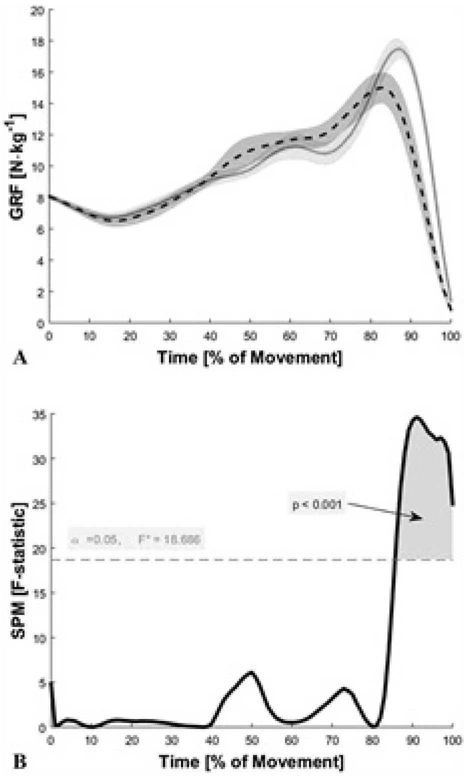

Figure 1.: A) Ensemble average (lines) and 95% confidence interval (shaded areas) data for normalized ground reaction forces (GRFs: [N·kg^{-1}]) of the barbell-lifter system during the hang-power clean (dotted line) and jump shrug (solid line). B) Statistical parametric mapping data (F-statistic) comparing the hang-power clean and jump shrug force-time series data. The dotted horizontal line designates the threshold for significance for the SPM procedure, and thus indicates where the time series data differ. SPM = statistical parametric mapping.

The SPM procedure indicated a significant difference between the vertical GRF of the HPC and JS between ∼85 and 100% of the movement phase (Figure 1B). Identically smooth random time series data would produce a cluster of this breadth with a probability of $p < 0.001$. Post hoc analysis showed that the vertical GRF of the JS during this phase was significantly greater than that of the HPC.

Velocity-Time Data

The curve analysis indicated significant differences between the vertical GRF of the HPC and JS between ∼72 and 76% (between $0.038 < p < 0.046$) and between ∼88 and 100% of the movement phase (all $p < 0.001$) (Figure 2A). Post hoc analysis showed that the vertical GRF of the JS were lower than the HPC during the first interval, but greater during the latter interval.

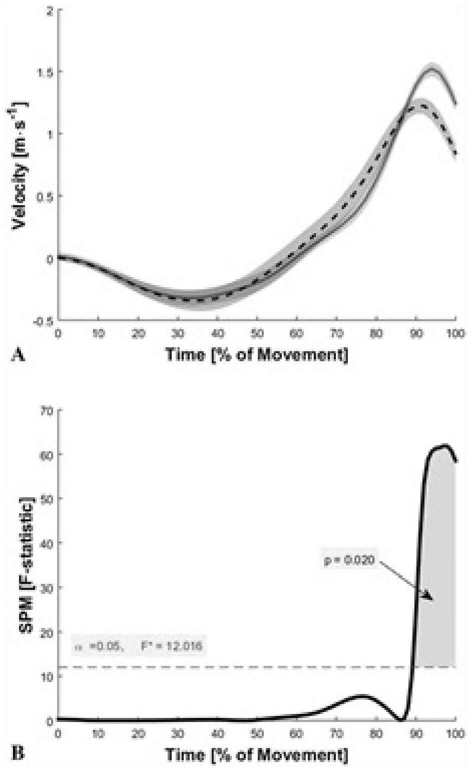

Figure 2.: A) Ensemble average (lines) and 95% confidence interval (shaded areas) data for barbell-lifter system velocity (velocity: [m·s^{-1}]) during the hang-power clean (dotted line) and jump shrug (solid line). B) Statistical parametric mapping data (F-statistic) comparing the hang-power clean and jump shrug velocity-time series data. The dotted horizontal line designates the threshold for significance for the SPM procedure, and thus indicates where the time series data differ. SPM = statistical parametric mapping.

The SPM procedure indicated a significant difference between the barbell-lifter system velocity during the HPC and JS between ∼90 and 100% of the movement phase (Figure 2B). Identically smooth random time series data would produce a cluster of this breadth with a probability of $p = 0.020$. Post hoc analysis showed that the barbell-lifter system velocity of the JS during this phase was significantly greater than that of the HPC.

Displacement-Time Data

Neither the SPM procedure nor the curve analysis indicated a significant difference between the barbell-lifter system position during the HPC and JS at any point during the movement phase (Figure 3A, B).

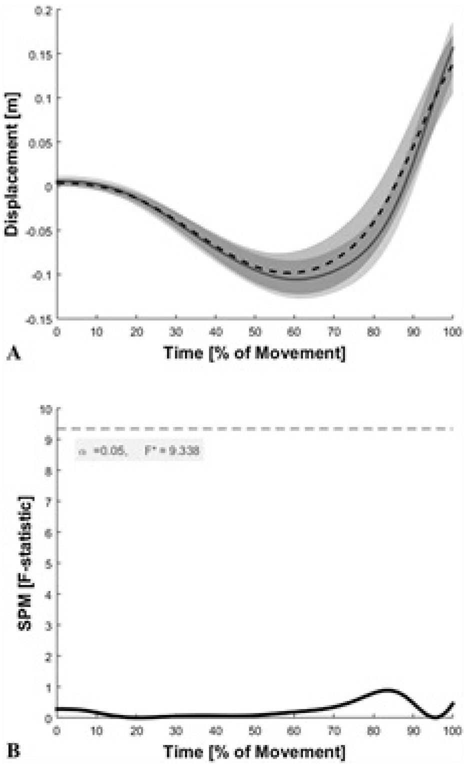

Figure 3.: A) Ensemble average (lines) and 95% confidence interval (shaded areas) data for barbell-lifter system position (position: [m]) during the hang-power clean (dotted line) and jump shrug (solid line). B) Statistical parametric mapping data (F-statistic) comparing the hang-power clean and jump shrug position-time series data. The dotted horizontal line designates the threshold for significance for the SPM procedure, and thus indicates where the time series data differ. SPM = statistical parametric mapping.

Power-Time Data

The curve analysis indicated significant differences between the barbell-lifter system power of the HPC and JS between ∼70 and 76% (between $0.032 < p < 0.037$) and between ∼84 and 100% of the movement phase (all $p < 0.001$) (Figure 4A). Post hoc analysis showed that the barbell-lifter system powers of the JS were lower than those of the HPC during the first interval, but greater during the latter interval.

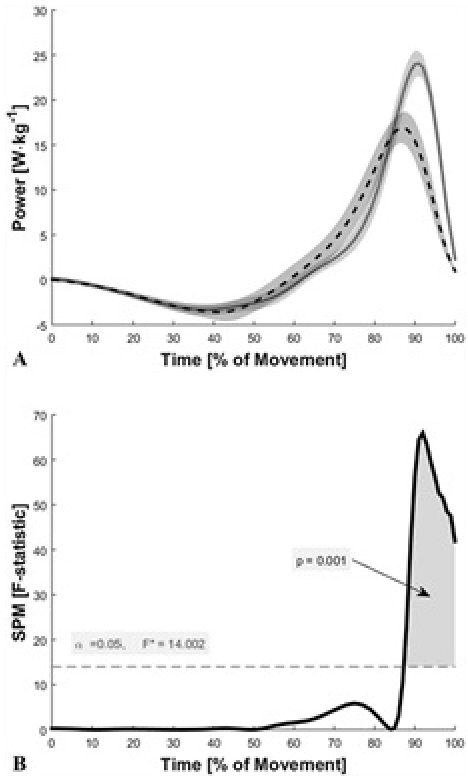

Figure 4.: A) Ensemble average (lines) and 95% confidence interval (shaded areas) data for normalized power (power: [W·kg^{-1}]) of the barbell-lifter system during the hang-power clean (dotted line) and jump shrug (solid line). B) Statistical parametric mapping data (F-statistic) comparing the hang-power clean and jump shrug power-time series data. The dotted horizontal line designates the threshold for significance for the SPM procedure, and thus indicates where the time series data differ. SPM = statistical parametric mapping.

The SPM procedure indicated a significant difference between the barbell-lifter system power of the HPC and JS between ∼90 and 100% of the movement phase (Figure 4B). Identically smooth random time series data would produce a cluster of this breadth with a probability of $p < 0.001$. Post hoc analysis showed that the barbell-lifter system power of the JS during this phase was significantly greater than that of the HPC.

Discussion

The purpose of this study was to investigate differences in the biomechanical time series curves during the HPC and the JS. The major novel findings of this study indicate that the JS is characterized by greater GRF and barbell-lifter system velocity and power outputs during the final 10% of the movement phase. Furthermore, the differences in mechanical outputs were more apparent when examining the results obtained from the SPM procedure than the curve analysis. The results of the current study may have significant implications for practitioners who use weightlifting derivatives in their programs and for researchers who analyze time series data.

During the last 10–15% of the movement phase, the GRF and barbell-lifter system power outputs were significantly greater for the JS than for the HPC. These findings are in good agreement with discrete peak kinetic data as well as time series data ([18–20]). For example, discrete peak force and peak power are greater during the JS than the HPC regardless of load (i.e., 30–80% of 1RM) ([20]). In addition, the JS also elicits markedly different force- and power-time characteristics compared with the HPC ([18,19]). More specifically, Suchomel and Sole ([18,19]) reported that force and power outputs during the last 20–25% of the JS are greater compared with the HPC. The results also revealed that the final 10% of the movement phase of the JS was characterized by greater barbell-lifter system velocities compared with the movement phase of the HPC. It therefore seems that the greater barbell-lifter system powers were driven by greater GRF and barbell-lifter system velocities. Although there is no comparable time series data for weightlifting derivatives, greater discrete peak barbell-lifter system velocities have been reported for the JS when compared with the HPC, regardless of the weight lifted ([20]). The reason for the difference in mechanical outputs between the 2 exercises has been attributed to the fact that the JS likely elicits greater extension of the 3 primary lower-extremity joints (i.e., hip, knee, and ankle) when compared with the HPC ([10,16,18–20]). Given that the intent of the JS is to jump as high as possible with the barbell, rather than catch the barbell as with the HPC, it is likely that the final portion of the movement phase of the JS is performed in a more impulsive manner, whereas some deceleration will occur during the HPC as the individual prepares to drop into the catch position, to receive the barbell near its peak displacement. It is also for this reason that we chose to compare the mechanical outputs at only 70% of 1RM because it is difficult to maximize effort and still effectively catch the barbell in the HPC.

The current study used 2 methods to compare the time series data from the HPC and JS. Both methods showed consistent differences in the final phases of both movements. The conclusion that, based on the time series comparison, the mechanical outputs during the JS are greater than during the HPC is therefore well supported by current and previous findings. However, the curve analysis also showed differences during other phases of the movements. Most notably, results from the curve analysis indicated that when compared with the HPC, the JS exhibited greater GRF from ∼46 to 50% of movement, and lower barbell-lifter system velocities and power from 72 to 76% and 70–76% of movement, respectively. Results from SPM, however, did not reveal differences in the time series data during any of these phases. The discrepancy between the results from the 2 methods likely reflects statistical issues related to the inappropriate application of curve analysis to compare time series data ([13–15]). Indeed, the probability distributions that are used to establish thresholds for statistical significance differ vastly between the 2 methods and suggests that the greater likelihood of the curve analysis to show statistical differences indicates a greater type I error rate for the curve analysis ([15]). This is especially important because the results from the curve analysis would lead to the erroneous conclusion that the mechanical outputs during certain phases of the HPC are greater than during the JS, which again is not supported when the data are analyzed with methods specifically designed for time series data.

The conclusions of this study should be interpreted considering several limitations. First, we used only 4 mechanical variables to characterize the center-of-mass biomechanics of the barbell-lifter system during each exercise. That said, 3 of the 4 variables provided a consistent interpretation of the findings of the current study. Moreover, the use of SPM as an analysis technique of the time series data and biomechanical differences between the 2 exercises provides a greater internal validity about the methods and statistical findings in the current study. Second, although the 4 mechanical variables adequately characterize the biomechanical behavior of the barbell-lifter system's center of mass, they offer no information about joint-level behavior. Given that joint-level behaviors, such as covariation of net joint moments and posture-related changes in effective mechanical advantage, can affect GRF, the conclusions of the current study should be interpreted in combination with results from studies that examined joint-level biomechanics ([10]). Finally, this study used a cross-sectional experimental design to compare the biomechanics of 2 exercises. It therefore remains to be determined whether long-term training with one specific exercise improves athletic performance over another exercise, even if one exercise is associated with greater mechanical outputs such as in the current study.

Practical Applications

The current study has significant implications for practitioners and researchers. The practical applications for practitioners relate to the prescription of weightlifting derivatives in resistance training programs. The results indicate that executing the JS leads to greater GRF as well as greater barbell-lifter system velocities and power outputs during the last 10–15% of the movement than the HPC. The greater mechanical outputs of the JS may point to a greater effort put forth by the athletes, which may also imply a greater potential training stimulus. Practitioners may thus want to consider including the JS into resistance training programs in addition to other, more traditional, weightlifting exercises. The practical applications for researchers relate to the discrepancy in results from the curve analysis or the SPM procedure. The results indicate that data from the curve analysis was more likely to show statistically significant differences between the exercises when compared with data from the SPM procedure. Given that the SPM procedure is specifically designed for comparing continuous time series data, the greater likelihood of the curve analysis to show statistical differences may indicate a greater type I error rate, which questions the use of curve analysis to compare biomechanical time series data, such as force-time curves etc.

References

1. Comfort P, Allen M, Graham-Smith P. Comparisons of peak ground reaction force and rate of force development during variations of the power clean. J Strength Cond Res 25: 1235–1239, 2011.
2. Comfort P, Allen M, Graham-Smith P. Kinetic comparisons during variations of the power clean. J Strength Cond Res 25: 3269–3273, 2011.
3. Comfort P, Dos'Santos T, Thomas C, McMahon JJ, Suchomel TJ. An investigation into the effects of excluding the catch phase of the power clean on force-time characteristics during isometric and dynamic tasks: An intervention study. J Strength Cond Res 32: 2116–2129, 2018.
4. 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 24: 112–120, 2008.
5. Cormie P, McBride JM, McCaulley GO. Power-time, force-time, and velocity-time curve analysis of the countermovement jump: Impact of training. J Strength Cond Res 23: 177–186, 2009.
6. Hoffman JR, Cooper J, Wendell M, Kang J. Comparison of Olympic vs. traditional power lifting training programs in football players. J Strength Cond Res 18: 129–135, 2004.
7. Hori N, Newton RU, Andrews WA, et al. Does performance of hang power clean differentiate performance of jumping, sprinting, and changing of direction? J Strength Cond Res 22: 412–418, 2008.
8. Hori N, Newton RU, Nosaka K, Stone MH. Weightlifting exercises enhance athletic performance that requires high-load speed strength. Strength Cond J 27: 50–55, 2005.
9. Kipp K, Chad H, Sabick MB. Correlations between internal and external power outputs during weightlifting exercise. J Strength Cond Res 27: 1025–1030, 2013.
10. Kipp K, Malloy PJ, Smith JC, et al. Mechanical demands of the hang power clean and jump shrug: A joint-level perspective. J Strength Cond Res 32: 466–474, 2018.
11. Newton RU, Kraemer WJ. Developing explosive muscular power: Implications for a mixed methods training strategy. Strength Cond J 16: 20–31, 1994.
12. Otto WH III, Coburn JW, Brown LE, Spiering BA. Effects of weightlifting vs. kettlebell training on vertical jump, strength, and body composition. J Strength Cond Res 26: 1199–1202, 2012.
13. Pataky TC. Generalized n-dimensional biomechanical field analysis using statistical parametric mapping. J Biomech 43: 1976–1982, 2010.
14. Pataky TC, Vanrenterghem J, Robinson MA. Zero- vs. one-dimensional, parametric vs. non-parametric, and confidence interval vs. hypothesis testing procedures in one-dimensional biomechanical trajectory analysis. J Biomech 48: 1277–1285, 2015.
15. Pataky TC, Vanrenterghem J, Robinson MA. The probability of false positives in zero-dimensional analyses of one-dimensional kinematic, force and EMG trajectories. J Biomech 49: 1468–1476, 2016.

16. Suchomel TJ, Comfort P, Stone MH. Weightlifting pulling derivatives: Rationale for implementation and application. Sports Med 45: 823–839, 2015.
17. Suchomel TJ, Nimphius S, Bellon CR, Stone MH. The importance of muscular strength: Training considerations. Sports Med 48: 765–785, 2018.
18. Suchomel TJ, Sole CJ. Force-time-curve comparison between weightlifting derivatives. Int J Sports Physiol Perf 12: 431–439, 2017.
19. Suchomel TJ, Sole CJ. Power-time curve comparison between weightlifting derivatives. J Sports Sci Med 16: 407–413, 2017.
20. Suchomel TJ, Wright GA, Kernozek TW, Kline DE. Kinetic comparison of the power development between power clean variations. J Strength Cond Res 28: 350–360, 2014.
21. Suchomel TJ, Wright GA, Lottig J. Lower extremity joint velocity comparisons during the hang power clean and jump shrug at various loads. Presented at XXXIInd International Conference of Biomechanics in Sports. Johnson City, TN, 2014.
22. Tricoli V, Lamas L, Carnevale R, Ugrinowitsch C. Short-term effects on lower-body functional power development: Weightlifting vs. vertical jump training programs. J Strength Cond Res 19: 433–437, 2005.
23. Winchester JB, Erickson TM, Blaak JB, McBride JM. Changes in bar-path kinematics and kinetics after power-clean training. J Strength Cond Res 19: 177–183, 2005.