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Mechanical Demands of the Hang Power Clean and Jump Shrug: A Joint-level Perspective

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RUNNING HEAD: Biomechanics of power exercises

ABSTRACT

The purpose of this study was to investigate the joint- and load-dependent changes in the mechanical demands of the lower extremity joints during the hang power clean (HPC) and the jump shrug (JS). Fifteen male lacrosse players were recruited from an NCAA DI team, and completed three sets of the HPC and JS at 30%, 50%, and 70% of their HPC 1-Repetition Maximum (1-RM HPC) in a counterbalanced and randomized order. Motion analysis and force plate technology were used to calculate the positive work, propulsive phase duration, and peak concentric power at the hip, knee, and ankle joints. Separate three-way analysis of variances were used to determine the interaction and main effects of joint, load, and lift type on the three dependent variables. The results indicated that the mechanics during the HPC and JS exhibit joint-, load-, and lift-dependent behavior. When averaged across joints, the positive work during both lifts increased progressively with external load, but was greater during the JS at 30% and 50% of 1-RM HPC than during the HPC. The JS was also characterized by greater hip and knee work when averaged across loads. The joint-averaged propulsive phase duration was lower at 30% than at 50% and 70% of 1-RM HPC for both lifts. Furthermore, the load-averaged propulsive phase duration was greater for the hip than the knee and ankle joint. The joint-averaged peak concentric power was the greatest at 70% of 1-RM for the HPC and at 30% to 50% of 1-RM for the JS. In addition, the joint-averaged peak concentric power of the JS was greater than that of the HPC. Furthermore, the load-averaged peak knee and ankle concentric joint powers were greater during the execution of the JS than the HPC. However, the load-averaged power of all joints differed only during the HPC, but was similar between the hip and knee joints for the JS. Collectively, these results indicate that compared to the HPC the JS is characterized by greater hip and knee positive joint work, and greater knee and ankle peak concentric joint power, especially if performed at 30 and 50% of 1-RM HPC. This study provides important novel information about the mechanical demands of two commonly used exercises and should be considered in the design of resistance training programs that aim to improve the explosiveness of the lower extremity joints.

Keywords: biomechanics; weightlifting derivatives; resistance training; optimal load; peak power

INTRODUCTION

Weightlifting exercises and their derivatives, such as the hang-power clean (HPC), are commonly used within strength and conditioning programs to increase explosive performance of the lower body (2, 3, 8, 10, 19)._ENREF_1 The frequent use of these exercises can be attributed to their biomechanical similarities to other athletic movements that require an explosive triple extension of the lower extremity joints (4, 7, 8, 19). Researchers have indicated that the ability to perform weightlifting movements is correlated to faster sprint and higher jump performances (1, 6)._ENREF_6 Moreover, the inclusion of weightlifting exercises leads to greater and broader improvements in jumping and sprinting performance compared to other forms of exercise (5, 16, 26)._ENREF_7

Recent research has focused on the jump shrug (JS) as a novel alternative to the HPC (18, 23-25). Although the JS shares mechanical similarities with the HPC, especially during the pull-phase, the major difference is that the JS eliminates the catch phase of the HPC (21), which may be a difficult skill to teach. The JS may also provide several additional benefits over the HPC in that its technique is less complex, more time efficient to teach and learn, and may enable a greater overload (20, 22). Research comparing the biomechanics of the JS and HPC indicates that the JS results in greater barbell-lifter system velocity, force, and power (25). While these results provide important information about the power of the lifter-barbell system, they offer no information about the power produced at the joint-level. Knowledge about the power produced at the lower extremity joints, however, would greatly facilitate the design of specific resistance programs that use weightlifting exercises and their derivatives. While previous research has indicated that the hip, knee, and ankle joint velocities were greater during the JS compared to the HPC (25), little is known about the joint-dependent power of the lower extremity joints during either exercise.

Given that any training effect is subject to the law of specificity, knowledge about the internal joint kinetics would provide important information that could be used in the program design process. Another issue to consider is the load-dependent behavior, because it is well documented that training at optimal loads – those that maximize power – is the most effective approach to improving maximal muscle power (9, 15, 17). The use of optimal loads during a training session is thus very important when specific adaptations, such as increased muscular power, are a primary goal. In addition, it would be of benefit to supplement data on joint-level mechanical power with the mechanistic contributors i.e., mechanical work and time during the propulsive phase. Such additional data would provide practitioners with a broader perspective about the mechanical demands and load-dependent behavior of the HPC and JS. The purpose of this study was therefore to determine the effects of changing external loads on the mechanical demands at the hip, knee, and ankle joint during the propulsive phase of the HPC and JS.

METHODS

Experimental Approach to the Problem

A repeated measures design was used to examine the differences in hip, knee, and ankle joint positive work, propulsive phase duration, and peak concentric power during HPC and JS performed across several relative loads. The dependent variables of joint power, work, and duration were used to characterize the mechanical demands experienced by the lower extremity joints during each exercise.

Subjects

Fifteen male, NCAA DI lacrosse players (Mean±SD; age: 20.1±1.2 years; height: 1.78±0.07 m; body mass: 80.4±8.1 kg; 1-RM HPC: 100.4±8.1 kg; relative 1-RM HPC: 1.25±0.13 $kg \cdot kg^{-1}$) were recruited for this study. All subjects were actively engaged in a yearly training program that involved weightlifting exercises, such as the HPC, and were tested during their off-season training phase. The study was approved by the University's Institutional Review Board and all subjects provided written informed consent before the beginning of any data collection.

Procedures

Subject Preparation. Eighteen reflective markers were attached to the pelvis, thigh, shank, and foot segments of the right lower extremity according to the standard Plug-in Gait marker set (Vicon, Oxford, UK). Reflective markers were attached with double-sided tape and secured with extra tape as necessary. After attaching the markers, each subject was asked to perform a static trial in which they stood in an anatomically neutral position.

Testing Protocol. Subjects began with a general dynamic warm-up that consisted of jumping jacks, lunges, bodyweight squats, unloaded and loaded (20 kg) vertical jumps. After the general warm-up, subjects proceeded to a specific warm-up that consisted of two sets of three repetitions of the HPC at 30% and 50% of 1RM of HPC 1-RM. The 1-RM HPC was based on results from 1-RM testing performed a week prior to the current study. Subjects then started with either the HPC or JS, and performed one work set of three repetitions each at 30%, 50%, and 70% of each subject's 1-RM 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., 50%, 70%, 30%). After completing all work sets for one lift, subjects then switched to perform the other, 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. All repetitions of the HPC and JS were performed using previously described technique (19, 21).

Data Collection and Processing. The three-dimensional positions of 12 reflective markers were recorded at 100 Hz with a 14-camera motion analysis system (Vicon, Oxford, UK). Ground reaction force data were recorded at 1000 Hz from two, in-ground force plates (AMTI, Watertown, MA, USA) and the feet of each subject were placed such that one foot was on each force plate. Vicon Nexus (Vicon, Oxford, UK) was used to simultaneously collect these kinematic and kinetic data during each HPC and JS repetition. The standard Plug-in Gait biomechanical model was then used to process the data from the static and dynamic trials and calculate hip, knee, and ankle joint biomechanics. Joint power output was normalized to each subject's body-mass. The direction of the joint power follows the convention that positive power indicates power production and that negative power indicates power absorption (Figure 1 & 2). Peak positive power from each joint were extracted for analysis during the concentric pull phase, which was defined as the time frame between the lowest point of the barbell and the point when the feet left the ground. Total positive work was then calculated from the integral of all positive joint power data during the concentric pull-phase (27). Propulsive phase duration was calculated as the sum of time points where joint power was positive during the extension of each joint. Data from each of the three trials were averaged into a three-trial average.

Insert Figures 1 & 2 about here

Statistical Analysis

Intraclass correlation coefficients were used to determine the test-retest reliability of all dependent variables. The statistical analysis for this study involved separate three-way repeated measures analysis of variance. The dependent variables within this analysis were power, work, and propulsive phase duration and the independent variables were lift type (HPC / JS), load (30 / 50 / 70), and joint (hip / knee / ankle). Analysis of any two-way interaction effects involved pooling (i.e., averaging) data across whichever variable was not part of the interaction (e.g., for the joint x lift interaction, global measures of dependent variables were calculated by averaging across all loads). Statistical assumptions were checked before data were analyzed. The standard of proof to show statistical significance for all analyses was set at a level of $\alpha = .05$. Bonferroni corrections were made during post-hoc testing to account for multiple comparisons ($\alpha = 0.017$). In addition, multi-variate (partial η^2) effect sizes and statistical power (power) are presented. Data are presented as Mean±SD. All statistical analyses were performed in SPSS 22.0 (IBM Corporation, Somers, NY, USA).

RESULTS

Reliability Data and Descriptive Statistics. Intraclass correlation coefficients for the dependent variables are displayed in Table 1. The descriptive data for the HPC and JS are displayed in Tables 2-4.

Insert Table 1 about here

Insert Table 2 about here

Insert Table 3 about here

Insert Table 4 about here

Positive Work. The three-way interaction between lift type, load, and joint was not significant. However, all three of the two-way interactions were significant: load x lift ($F_{2,48} = 10.5$, p = 0.001, $\eta^2 = 0.304$, power = 0.98), joint x lift ($F_{2,48} = 22.0$, p = 0.001, $\eta^2 = 0.479$, power = 1.00), joint x load ($F_{2,48} = 21.7$, p = 0.001, $\eta^2 = 0.475$, power = 1.00). Post-hoc testing for the load x lift interaction indicated that, when averaged across joints, there was a significant load effect on joint work for the HPC (Figure 3A: 30% vs. 50%: p = 0.002; 30% vs. 70%: p = 0.001; 50% vs 70%: p = 0.002) and the JS (Figure 3A: 30% vs. 50%: p = 0.015; 30% vs. 70%: p = 0.001; 50% vs 70%: p = 0.005), but the joint-averaged work for the HPC and JS only differed at 30% and 50% of 1-RM (p = 0.001 at both loads). Post-hoc testing for the joint x lift interaction indicated that load-averaged joint work of the HPC and JS differed only at the hip (p = 0.001) and knee (p = 0.003) joints (Figure 3B). Post-hoc testing for the joint x load interaction indicated that, when averaged across lifts, only the hip and ankle joints exhibited load-dependent behavior in work (Figure 4). More specifically, the lift-averaged work was greater at 50% than at 30% of 1-RM (Hip: p = 0.016, Ankle: p = 0.001), greater at 70% than at 50% of 1-RM (p = 0.001 for both joints), and greater at 70% than at 30% of 1-RM (p = 0.001 for both joints).

Insert Figure 3 about here

Insert Figure 4 about here

Propulsive Phase Duration. Neither the three-way nor any of the two-way interactions between lift type, load, and joint were significant. There were, however, significant main effects for load ($F_{2,48}$ = 13.062, p = 0.001, η^2 = 0.352, power = 1.00) and joint ($F_{2,48}$ = 208.9, p = 0.001, η^2 = 0.896, power = 1.00). Post-hoc testing for these main effects indicated that propulsive phase duration differed between the 30% and 50% load (p = 0.012) and between 30% and 70% load (p = 0.006) regardless of lift or joint (Figure 5A), and that propulsive phase duration was greater for the hip than the knee and ankle joint (hip vs. knee: p = 0.001; hip vs. ankle: p = 0.001) regardless of load or lift (Figure 5B).

Insert Figure 5 about here

Peak Concentric Power. The three-way interaction between lift type, load, and joint was not significant. However, all three of the two-way interactions were significant: load x lift ($F_{2,48}$ = 30.5, p = 0.001, η^2 = 0.559, power = 1.00), joint x lift ($F_{2,48}$ = 28.0, p = 0.001, η^2 = 0.539, power = 1.00), joint x load ($F_{2,48}$ = 6.9, p = 0.001, η^2 = .223, power = 0.99). Post-hoc testing for the load x lift interaction indicated that, when averaged across joints, there was a significant load effect on HPC joint power (Figure 6A: 30% vs. 50%: p = 0.001; 30% vs. 70%: p = 0.001; 50% vs 70%: p = 0.001), whereas for the JS they only differed between the 30% and 70% load (p = 0.015), and between 50% and 70% load (p = 0.010). Furthermore, JS joint power, when averaged across joints, at all loads was greater than HPC joint power (all p = 0.001). Post-hoc testing for the joint x lift interaction indicated that, when averaged across loads, there was a significant joint effect on HPC power (Figure 6B: hip vs. knee: p = 0.001; hip vs. ankle: p = 0.009; knee vs. ankle: p = 0.001), whereas for the JS they differed between the ankle and the knee joints (p = 0.016), as well as between the ankle and the hip joint (p = 0.001). Furthermore, JS load-averaged power was greater at the knee and ankle joints (both p = 0.001) compared to the HPC. Post-hoc testing for the joint x load interaction indicated that, when averaged across lifts, only the hip joint exhibited load-dependent behavior in power (Figure 7). More specifically, the hip joint lift-averaged power at 30% 1-RM was less than the power at 50% and 70% 1-RM (both p = 0.001).

Insert Figure 6 about here

Insert Figure 7 about here

DISCUSSION

The purpose of this study was to determine the effects of changing external loads on the mechanical demands at the hip, knee, and ankle joint during the propulsive phase of the HPC and JS. The major novel findings of this study collectively indicate that the JS is characterized by greater hip, knee, and ankle joint mechanical demands compared to the HPC, especially if it is performed at 30-50% of 1-RM HPC. The greater mechanical demands were attributed to greater positive work and peak power during the concentric phase of each exercise, rather than the duration of that phase.

Joint-averaged positive work and peak concentric power during the execution of the HPC and JS were dependent on the load that was lifted. When averaged across joints, the positive work was greater during the JS at 30% and 50% of 1-RM HPC than during the HPC, whereas the peak concentric power during the JS was greater across all loads. Furthermore, joint-averaged peak concentric power during the HPC peaked at 70% of 1-RM HPC, but peaked at 30% and 50% during the JS. These results agree with previous reports on optimal loads for maximal power production of the entire barbell-lifter system during lower-body resistance exercises, such as the HPC (8, 17). Further, these results also agree with findings that examined joint velocities during the HPC and JS (25), but extend our knowledge to the internal joint kinetics that are paramount to understanding joint-specific loading behaviors. Given that joint-averaged work and power were greater during the JS compared to the HPC at both 30 and 50% of 1-RM HPC, it appears that a more effective training stimulus could be imposed on the lower body with these particular loads. These findings partially support those of Suchomel et al. (24) who reported that regardless of external load, the mechanical power of the lifter-barbell system during the JS was greater than during the HPC. These same authors also reported opposite trends in load that maximized mechanical power of the lifter-barbell system for the HPC (19) and JS (18). It thus appears that joint-averaged power reflects the mechanical power of the lifter-barbell system for both the HPC and JS, which is similar to what has been reported for the traditional clean (11). Whether this is the case for joint-averaged work, however, is questionable because joint-averaged positive work did not differ between exercises at 70% of 1-RM HPC.

Load-averaged positive work and peak concentric power during the execution of the HPC and JS were also dependent on the joint that was examined. Although these findings stand in contrast to Kipp et al. (12), who did not find any joint-dependent variation in power as subjects performed the clean exercise, the range of loads used in that study was much narrower and likely accounts for the discrepancy to the current study. Nonetheless, when averaged across loads, the positive work during the JS was greater for the hip and knee joint than compared to the HPC, with a much greater relative difference existing between the lifts noted at the hip joint. With respect to peak concentric power, the JS exhibited greater knee and ankle joint power compared to the HPC. Collectively, these joint-dependent differences indicate a greater mechanical demand placed on the lower extremity muscles during the JS compared to the HPC, regardless of the external load. In regards to joint-specific differences for each lift, the load-averaged results indicate that the HPC was characterized by large magnitudes of positive ankle joint work and hip and ankle joint power, whereas the JS was characterized by large magnitudes of hip and ankle joint work and ankle and knee joint power. It is also interesting to briefly consider these findings in light of the comparatively small magnitudes of knee joint work and power during the HPC considering that this lift is often associated with training for explosive performance of the knee extensor muscles, often in a stretch-shortening cycle (SSC) fashion. The current findings, however, question this assertion and suggest that the HPC is actually characterized by much greater work and power contributions from the ankle and hip joint.

When averaged across lifts, only the hip joint exhibited load-dependent behavior for positive joint work and concentric peak power. Further, the ankle joint exhibited load-dependent behavior for only positive joint work. Again, these findings are in contrast to Kipp et al. (12) who reported a lack of variation in joint power across joints as subjects performed the clean exercise. However, these authors did report load-dependent behavior of the hip joint torques in that greater loads (i.e., 65% vs. 85% of 1-RM) were characterized by greater joint torques, which partially agrees with the current study's findings on hip joint work and power. The discrepancy between the power findings may also be due to the nature of the exercises and the subjects who were recruited for those studies. Kipp et al. (11-14) recruited experienced weightlifters to perform the clean exercise whereas the current study recruited lacrosse players to perform the HPC and JS. Still, the current findings suggest that the mechanical demands of the hip, and to some extent the knee, extensor muscles increase with load for both the HPC and JS.

It was surprising that propulsive phase duration was not subject to any statistical interactions between the independent variables and that only main effects were noted for the dependent variables. Specifically, the joint-averaged propulsive phase duration was shorter at 30% than at 50% and 70% of 1-RM HPC for both the JS and HPC. The slowing in propulsive phase duration with an increase in load seems to reflect basic force-velocity behavior during both lifts. Further, the load-averaged propulsive phase duration was significantly greater for the hip than both the knee and ankle joints. At initial inspection, it may appear odd that the hip joint should extend for a much longer time period than the knee and ankle joints, but the earlier extension may simply reflect the lifters' use of a technique that is similar, albeit not identical, to the double knee bend technique where the knees continue to flex during the countermovement in order to facilitate an SSC-type muscle action of the knee extensor muscles during the concentric phase. This assertion, however, is in contradiction to the finding of smaller positive knee joint work, and to some extent reflects the aforementioned lack of knowledge about joint-specific function during specific weightlifting derivatives.

The results of this study should be interpreted in light of several limitations. First, the population of subjects for this study consisted of males from an NCAA DI lacrosse team, which may affect the generalizability of results to other populations, such as females or athletes from other sports. Second, the current study only reported on positive joint work, propulsive phase duration, and concentric joint power. However, examination of, for example joint torques and impulse may provide more insight into load- and joint-dependent behavior during the JS and HPC. Third, the current study focused on and reported data from only the concentric-phase, and not the eccentric or impact phase of the chosen lifts. Investigating the mechanical demands during these phases may provide additional information that is relevant to the exercise selection and program design process. While the examination of eccentric phase variables of the HPC or JS were beyond the scope of the current study, a brief qualitative look at the time-series data presented in Figures 1 & 2 indicated relatively little to no work done at the knee and ankle during the eccentric phase. This is an interesting finding because the balance between positive and negative work is typically used to describe the biomechanical role and function of a joint during movement (27). Given the general lack of joint-level investigations within the weightlifting and weightlifting derivative literature, this would perhaps be a fruitful avenue for future research.

PRACTICAL APPLICATIONS

The current study has practical implications regarding the prescription of weightlifting derivatives in resistance training programs. The results indicate that the JS produces comparable or greater concentric-phase joint work and power than the HPC depending on the specific joint. More specifically, compared to the HPC, the JS was characterized by greater hip and knee positive joint work, and greater knee and ankle peak concentric joint power. These differences were accentuated at lighter loads of 30-50% 1-RM, which complements previous research that has examined lifter-barbell system power output during the JS and HPC (18, 24, 25). Due to the mechanical stimulus and effort required by the athletes during the JS, it is suggested that practitioners consider implementing this exercise in resistance training programs concurrently with other weightlifting derivatives. In order for athletes to receive the greatest mechanical stimulus, it is recommended that practitioners prescribe loads of approximately 70% and 30-50% 1-RM for the HPC and JS, respectively. While both the HPC and JS may be prescribed in a variety of training phases, it appears that the JS may have greater versatility due to its comparable or larger joint work and peak power across all loads. However, taking previous recommendations into account (8-10, 19-21, 23-25), the athlete may be best served if the HPC is prescribed during absolute strength or strength-speed training blocks and the JS is prescribed during speed-strength training blocks.

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FIGURE LEGENDS

Figure 1. Sample hip (black line), knee (light gray line), and ankle (dark gray line) joint power-time data during the Hang-Power Clean with external loads of A) 30%, B) 50%, and C) 70% of 1-RM HPC.

Figure 2. Sample hip (black line), knee (light gray line), and ankle (dark gray line) joint power-time data during the Jump Shrug with external loads of A) 30%, B) 50%, and C) 70% of 1-RM HPC.

Figure 3. Joint-averaged (A) and load-averaged (B) positive work. Grey bars = Hang-Power Clean, Black bars = Jump Shrug. [*] Indicates post-hoc difference between Hang-Power Clean and Jump Shrug. Note: For clarity only lift-dependent post-hoc effects are shown.

Figure 4. Lift-averaged positive work for all joints and loads. Light grey bars = 30%, dark grey bars = 50%, black bars = 70% of 1-RM HPC.

Figure 5: Joint-averaged (A) and load-averaged (B) propulsive phase duration. Grey bars = Hang-Power Clean, Black bars = Jump Shrug.

Figure 6. Joint-averaged (A) and load-averaged (B) peak concentric power. Grey bars = Hang-Power Clean, Black bars = Jump Shrug. [*] Indicates post-hoc difference between Hang-Power Clean and Jump Shrug. Note: For clarity only lift-dependent post-hoc effects are shown.

Figure 7. Lift-averaged power for all joints and loads. Light grey bars = 30%, dark grey bars = 50%, black bars = 70% of 1-RM HPC.

Table 1: Intraclass correlation coefficients results for positive mechanical work, duration, and peak positive mechanical power for the hip, knee, and ankle joints during the propulsive (i.e., concentric) phase of the Hang-Power Clean (HPC) and the Jump Shrug (JS) at 30%, 50%, and 70% of HPC 1-RM.

	Hang-Power Clean			**Jump Shrug**		
Variable	30%	50%	70%	30%	50%	70%
Positive Work						
Hip	.869	.673	.793	.937	.823	.933
Knee	.789	.603	.907	.744	.844	.668
Ankle	.888	.859	.953	.978	.773	.952
Duration						
Hip	.863	.862	.940	.950	.758	.899
Knee	.649	.853	.645	.701	.761	.841
Ankle	.769	.765	.630	.632	.850	.900
Peak Power						
Hip	.832	.685	.854	.909	.720	.956
Knee	.962	.921	.967	.967	.964	.947
Ankle	.862	.811	.926	.981	.923	.877

Table 2: Mean±SD for positive mechanical work (J·kg^{-1}) for the hip, knee, and ankle joints during the propulsive (i.e., concentric) phase of the Hang-Power Clean (HPC) and the Jump Shrug (JS) at 30%, 50%, and 70% of HPC 1-RM.

	HPC			**JS**		
Variable	30%	50%[*]	70%[*†]	30%[#]	50%[*‡]	70%[*†]
Hip[∏]	1.06 ± 0.24	1.34 ± 0.17	1.61 ± 0.26	1.12 ± 0.30	1.24 ± 0.23	1.38 ± 0.30
Knee[∏]	0.09 ± 0.08	0.10 ± 0.06	0.13 ± 0.09	0.18 ± 0.08	0.19 ± 0.10	0.17 ± 0.13
Ankle	0.46 ± 0.25	0.62 ± 0.22	0.86 ± 0.25	1.12 ± 0.28	1.16 ± 0.23	1.27 ± 0.21

[*] = significantly greater joint-averaged work compared to 30% 1RM within HPC and JS ($p < 0.01$)

[†] = significantly greater joint-averaged work compared to 50% 1RM within HPC and JS ($p < 0.01$)

[#] = significantly greater joint-averaged work compared to HPC at 30% 1RM ($p < 0.01$)

[‡] = significantly greater joint-averaged work compared to HPC at 50% 1RM ($p < 0.01$)

[∏] = significantly different load-averaged joint work between exercises ($p < 0.01$)

Table 3: Mean±SD for the duration (ms) of the propulsive (i.e., concentric) phase of the hip, knee, and ankle joints during the Hang-Power Clean (HPC) and the Jump Shrug (JS) at 30%, 50%, and 70% of HPC 1-RM.

	HPC			**JS**		
Variable	30%	50%*	70%*	30%	50%*	70%*
Hip†	288 ± 43	328 ± 58	356 ± 45	303 ± 45	328 ± 58	371 ± 38
Knee	165 ± 26	181 ± 70	195 ± 22	154 ± 11	184 ± 59	192 ± 15
Ankle	155 ± 50	226 ± 135	218 ± 41	143 ± 37	166 ± 42	185 ± 28

* = significant main effect indicating longer propulsive phase duration compared to 30% 1RM, regardless of joint or lift ($p < 0.05$)

† = significantly greater propulsive phase duration compared to knee and ankle joints, regardless of load or lift ($p < 0.01$)

Table 4: Mean±SD for peak positive mechanical power ($W\cdot kg^{-1}$) for the hip, knee, and ankle joints during the propulsive (i.e., concentric) phase of the Hang-Power Clean (HPC) and the Jump Shrug (JS) at 30%, 50%, and 70% of HPC 1-RM.

	HPC			**JS**[‡¶]		
Variable	30%	50%[*]	70%[*†]	30%[#]	50%[#]	70%
Hip[∏&]	8.2 ± 1.6	10.1 ± 1.9	11.2 ± 2.0	8.9 ± 2.2	9.8 ± 2.3	9.1 ± 2.7
Knee	3.5 ± 2.6	4.2 ± 2.2	4.7 ± 2.9	13.0 ± 5.1	11.7 ± 4.6	10.8 ± 4.0
Ankle[∏^]	5.9 ± 3.1	7.4 ± 2.6	8.9 ± 2.4	14.9 ± 3.4	14.4 ± 2.8	13.7 ± 1.7

[*] = significantly greater joint-averaged power compared to 30% 1RM within HPC ($p < 0.01$)

[†] = significantly greater joint-averaged power compared to 50% 1RM within HPC ($p = 0.001$)

[#] = significantly greater joint-averaged power compared to 70% 1RM within JS ($p < 0.05$)

[‡] = significantly greater joint-averaged power compared to HPC at 30%, 50%, and 70% 1RM (all $p = 0.001$)

[∏] = significantly greater load-averaged power compared to the knee joint within HPC ($p < 0.01$)

[&] = significantly different load-averaged power compared to the ankle joint within HPC and JS ($p < 0.01$)

^ = significantly greater load-averaged power compared to the hip joint with JS ($p = 0.001$)

[¶] = significantly greater load-averaged power compared to the knee and ankle joint power of the HPC (both $p = 0.001$)

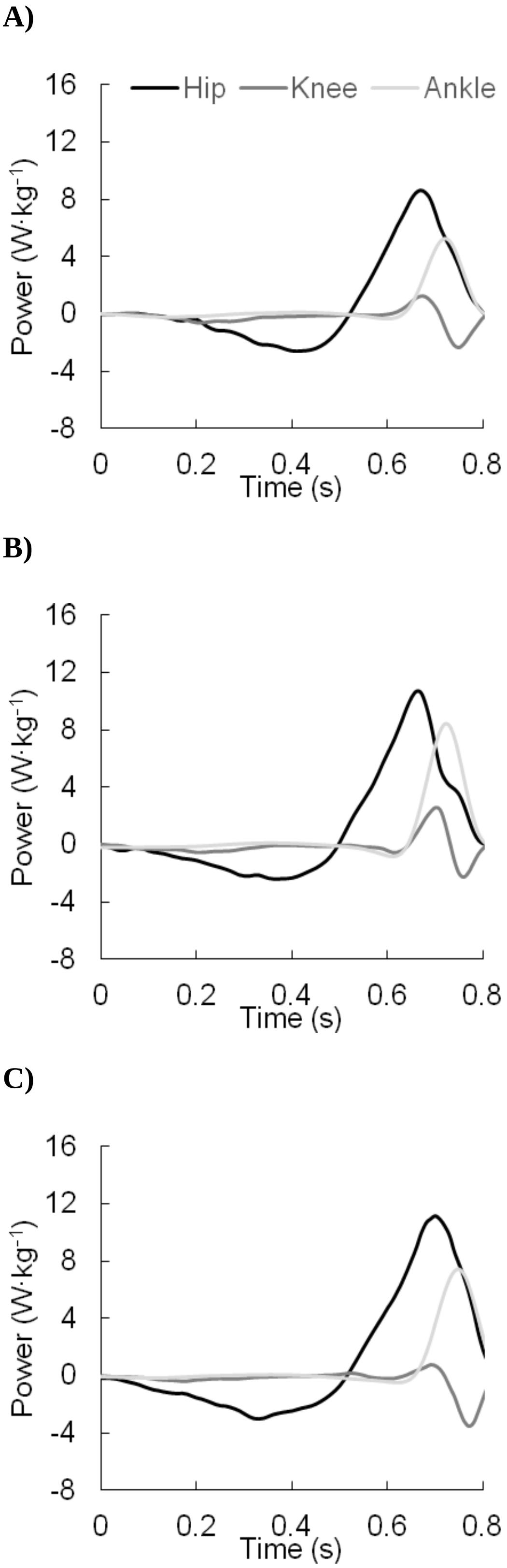
A)
Hip
Knee
Ankle
Power (W·kg-1)
16
12
8
4
0
-4
-8
0
0.2
0.4
0.6
0.8
Time (s)
B)
Power (W·kg-1)
16
12
8
4
0
-4
-8
0
0.2
0.4
0.6
0.8
Time (s)
C)
Power (W·kg-1)
16
12
8
4
0
-4
-8
0
0.2
0.4
0.6
0.8
Time (s)

Figure 1

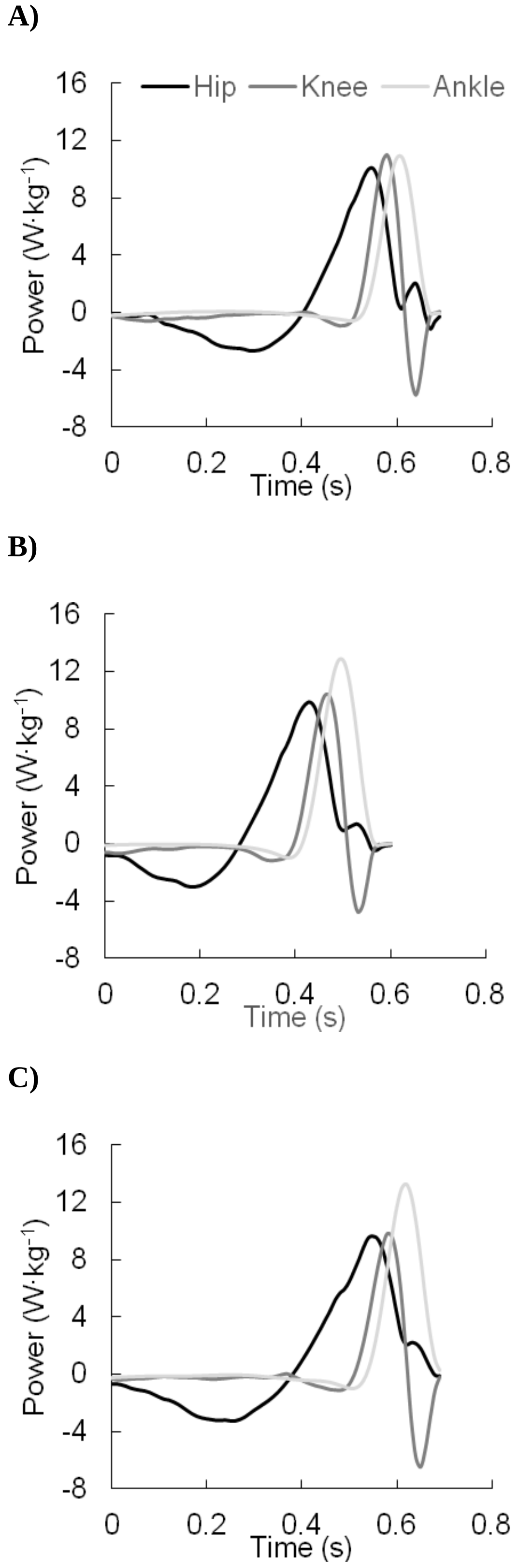
A)
Hip
Knee
Ankle
Power (W·kg⁻¹)
16
12
8
4
0
-4
-8
0
0.2
0.4
0.6
0.8
Time (s)
B)
Power (W·kg⁻¹)
16
12
8
4
0
-4
-8
0
0.2
0.4
0.6
0.8
Time (s)
C)
Power (W·kg⁻¹)
16
12
8
4
0
-4
-8
0
0.2
0.4
0.6
0.8
Time (s)

Figure 2

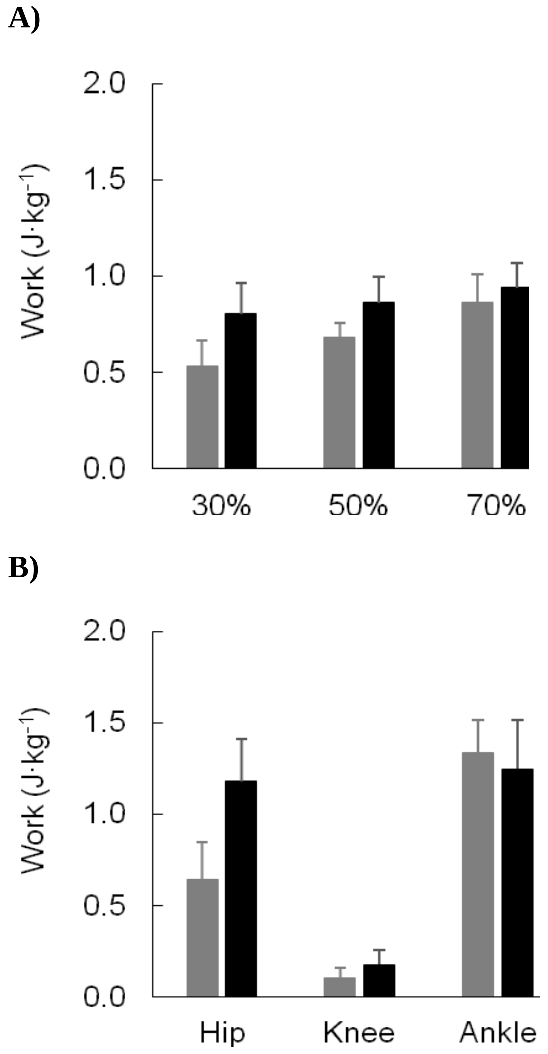

Figure 3

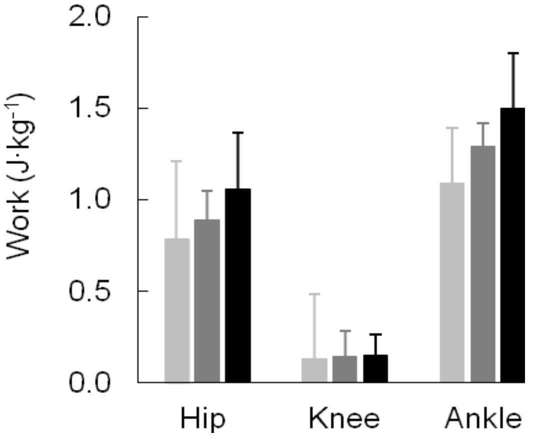

Figure 4

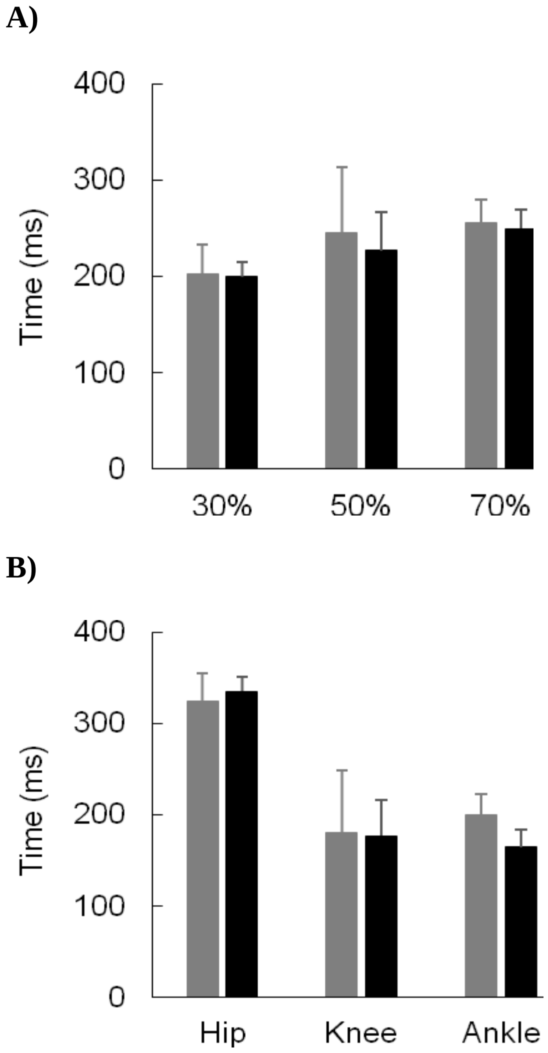
A)
400
300
200
100
0
Time (ms)
30%
50%
70%
B)
400
300
200
100
0
Time (ms)
Hip
Knee
Ankle

Figure 5

A)

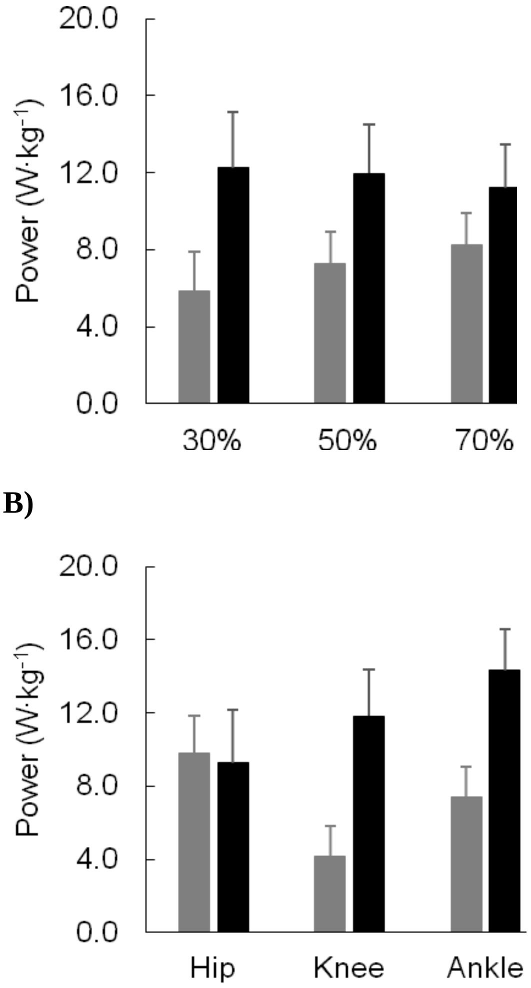

Figure 6

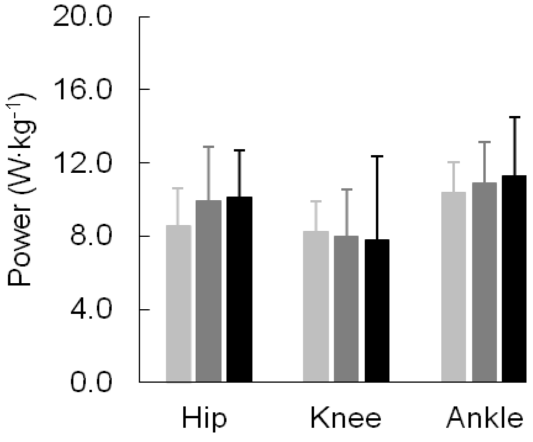

Figure 7