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Comparison of Joint Work During Load Absorption Between Weightlifting Derivatives

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Abstract

Suchomel, TJ, Giordanelli, MD, Geiser, CF, and Kipp, K. Comparison of joint work during load absorption between weightlifting derivatives. *J Strength Cond Res* 35(2S): S127–S135, 2021—This study examined the lower-extremity joint-level load absorption characteristics of the hang power clean (HPC) and jump shrug (JS). Eleven Division I male lacrosse players were fitted with 3-dimensional reflective markers and performed 3 repetitions each of the HPC and JS at 30, 50, and 70% of their 1 repetition maximum (1RM) HPC while standing on force plates. Load absorption joint work and duration at the hip, knee, and ankle joints were compared using 3-way repeated-measures mixed analyses of variance. Cohen's d effect sizes were used to provide a measure of practical significance. The JS was characterized by greater load absorption joint work compared with the HPC performed at the hip ($p < 0.001$, $d = 0.84$), knee ($p < 0.001$, $d = 1.85$), and ankle joints ($p < 0.001$, $d = 1.49$). In addition, greater joint work was performed during the JS compared with the HPC performed at 30% ($p < 0.001$, $d = 0.89$), 50% ($p < 0.001$, $d = 0.74$), and 70% 1RM HPC ($p < 0.001$, $d = 0.66$). The JS had a longer loading duration compared with the HPC at the hip ($p < 0.001$, $d = 0.94$), knee ($p = 0.001$, $d = 0.89$), and ankle joints ($p < 0.001$, $d = 0.99$). In addition, the JS had a longer loading duration compared with the HPC performed at 30% ($p < 0.001$, $d = 0.83$), 50% ($p < 0.001$, $d = 0.79$), and 70% 1RM HPC ($p < 0.001$, $d = 0.85$). The JS required greater hip, knee, and ankle joint work on landing compared with the load absorption phase of the HPC, regardless of load. The HPC and JS possess unique load absorption characteristics; however, both exercises should be implemented based on the goals of each training phase.

Introduction

The weightlifting movements (i.e., snatch, clean, and jerk) and their catching derivatives (e.g., power snatch, hang power clean [HPC], etc.) are popular exercises to implement within resistance training programs for the development of lower-extremity strength and power. In fact, previous research has indicated that training with weightlifting movements has been shown to produce superior strength-power adaptations compared with traditional resistance training (^{1,3,4,19}), jump training (^{37,38}), and kettlebell training (²⁴). This is not surprising, given their ability to generate greater relative power outputs during the triple extension of the hip, knee, and ankle (plantar flexion) joints compared with other resistance training exercises (¹⁷). Additional literature has indicated that the ability to perform weightlifting movements strongly correlates with jumping ability (^{2,20}) and that weightlifting movements can be used to develop sprint speed (¹⁴).

An additional benefit of weightlifting movements and their catching derivatives (i.e., those that include the catch phase) may be the ability to absorb an external load. In fact, some may argue that the catch phase of these movements may simulate an impact experienced in sports such as American football and rugby (²⁹). Despite the large body of literature that has examined the concentric phase of weightlifting catching derivatives (^{5–7,9,12,13,20,21,26,32,35}), only one previous study has examined load absorption characteristics. Moolyk et al. (²³) indicated that the lower-extremity joint work completed during the clean and power clean exercises was greater or similar to that of jump landing and drop landing. These results led the authors to conclude that the load absorption phase of weightlifting movements may be used to train the muscular strength required for impact actions, such as jumping landing tasks. Given the benefits of both the concentric and load absorption phases of weightlifting catching derivatives, there is little doubt as to why these movements have become a staple in so many resistance training programs.

Although weightlifting catching derivatives may be featured more exclusively in strength and conditioning programs, a growing body of literature indicates that weightlifting pulling derivatives (i.e., those that omit the catch phase) may produce similar (^{5,6}) or greater (^{22,32,33,35,36}) force-velocity characteristics during the concentric phase of the movement. Due to the elimination of the catch phase, loads greater than the 1 repetition maximum (1RM) of a weightlifting catching derivative may be prescribed (^{8,10,18}), which may allow for enhanced

force production characteristics to be developed. Similarly, weightlifting pulling derivatives such as the jump shrug (JS) and hang high pull may also produce greater velocities compared with weightlifting catching derivatives (35). Given the above benefits and others that have been discussed (28,29), the implementation of weightlifting pulling derivatives with weightlifting catching derivatives may be beneficial.

Similar to the research completed on weightlifting catching derivatives, the majority of the research on weightlifting pulling derivatives has examined the concentric phase of the movement (5,6,8,10,22,25,27,32–36,39). However, given the potential of weightlifting catching derivatives to train individuals to absorb an external load (23), research examining the ability of weightlifting pulling derivatives to train similar characteristics is needed. Two previous studies examined the load absorption characteristics of weightlifting pulling derivatives and compared them with weightlifting catching derivatives (11,31). Collectively, these studies indicated that weightlifting pulling derivatives may produce similar or greater load absorption force-time characteristics (i.e., work, mean force, duration) compared with the examined weightlifting catching derivatives. It should be noted, however, that the recent studies did not examine joint-level kinetics, making it difficult to compare their findings with those of Moolyk et al. (23). To determine the potential of weightlifting pulling derivatives to train an individual's ability to absorb an external load, research comparing the joint-level load absorption characteristics of a weightlifting catching and pulling derivative is needed. Therefore, the purpose of this study was to examine the lower-extremity joint-level load absorption characteristics of the HPC and JS performed at several different loads. It was hypothesized that the JS would produce greater load absorption demands compared with the HPC regardless of the external load used.

Methods

Experimental Approach to the Problem

A repeated-measures design was used to examine the differences in hip, knee, and ankle joint work and loading duration during the load absorption phase of the HPC and JS performed with several relative loads. Each participant was fitted with 3-dimensional reflective markers and performed 3 repetitions each of the HPC and JS at 30, 50, and 70% of their 1RM HPC during a single testing session. Load absorption joint work and duration were used to characterize the mechanical demands experienced by the lower-extremity joints during the load absorption phase of each exercise.

Subjects

Thirteen male, NCAA DI lacrosse players (mean \pm 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·kg⁻¹) were recruited for this study. The athletes were actively engaged in a resistance training program that involved weightlifting movements, such as the HPC, and were tested during their off-season training phase. The current study was approved by Marquette University's Institutional Review Board, and all participants provided written informed consent.

Procedures

To begin each testing session, participants were fitted with 18 reflective markers attached to the pelvis, thigh, shank, and foot segments of the right lower extremity based on the standard plug-in gait marker set (Vicon, Oxford, United Kingdom). The markers were attached with double-sided tape and secured with extra tape as necessary. After the placement of the markers, the participants were asked to perform a static trial in which they stood in an anatomically neutral position.

After the participants completed the static trials, a general warm-up that consisted of jumping jacks, lunges, bodyweight squats, and unloaded and loaded (20 kg) vertical jumps was performed. The participants then performed a specific HPC warm-up that consisted of 2 sets of 3 repetitions of the HPC at 30 and 50% of their

1RM. The warm-up loads were based on the results from 1RM testing that was completed as part of the participants' training programs a week before the current study. After the warm-up was completed, participants began performing testing repetitions with either the HPC or JS, and performed one work set of 3 repetitions each at 30, 50, and 70% of each participant's 1RM HPC. The load percentages were based off of the HPC 1RM and were the same for each exercise. The exercise that was tested first (i.e., HPC or JS) was counterbalanced, and the order of work sets was randomized (e.g., 50, 70, 30%). After all the work sets for the first exercise were complete, participants then performed the work sets for the other exercise using the same random order of loads as the previous exercise. Each exercise set was performed with 20 seconds of rest between each repetition and 90 seconds of rest between each set. All HPC and JS repetitions were performed using previously described techniques (^{26,30}). The movement sequence for both exercises is depicted in Figures 1 and 2. Briefly, each movement started from the midhigh (power) position (¹⁵). While keeping their elbows extended, the participants performed a countermovement with the barbell down their anterior thigh to a position above their patellae by flexing at hip and shifting their hips posteriorly. On reaching a position above the patellae and without pausing, the participants then transitioned back to the midhigh (power) position. On reaching this position, the participants rapidly extended their hip, knee, and ankle (plantar flexion) joints (i.e., second pull) and elevated the barbell (e.g., HPC) or "jumped as high as possible" (e.g., JS). After the barbell was elevated by the second pull and driving their elbows upward during the HPC, the participants rapidly rotated their elbows around the barbell while dropping into a semisquat position, and absorbed the load by racking the weight across their anterior deltoids. After the second pull and jump phase of the JS, the participants returned to the ground and absorbed the load by landing in the midhigh (power) position.



Figure 1.: Hang power clean exercise sequence.



Figure 2.: Jump shrug exercise sequence.

Twelve, 3-dimensional reflective markers were recorded at 100 Hz with a 14-camera motion analysis system (Vicon). Vertical ground reaction force data were recorded using 2, in-ground force plates (AMTI, Watertown, MA, USA) sampling at 1,000 Hz. Hang power clean and JS kinematic and kinetic data were collected simultaneously using Vicon Nexus (Vicon). To process the data from the static and dynamic trials and calculate hip, knee, and ankle joint biomechanics, the standard plug-in gait biomechanical model was used. The model uses the dot product between joint angular velocity and net joint moment to calculate mechanical joint power. Total work was then calculated from the integral of all the joint power data during the load absorption phase (⁴⁰). Within the model, the net joint moments are already normalized to body mass, and the total amount of joint work completed is thus expressed relative to the participants' body mass. Analysis of any variables during the load absorption phase was limited to the period between when the feet were in contact with the ground during the catch of the HPC, or landing of the JS, and the return to an upright standing position. More specifically, the integral time for negative joint work and the duration of the load absorption phase for each joint was defined as the period when the joint power was negative (i.e., a joint was flexing in the presence of an extension moment) during the catch and landing phases described above. In all cases, a distinct foot contact was

present and thus clearly demarcated these phases. Data from each of the 3 trials were averaged into a 3-trial average. Potential outliers were identified as data points that were more than 3 SDs away from the group mean.

Statistical Analyses

Test-retest reliability of load absorption joint work and duration was determined using 2-way mixed-model intraclass correlation coefficients. Three, 3-way (Exercise × Load × Joint) repeated-measures analysis of variance with Bonferroni post hoc comparisons were used to examine the differences in load absorption joint work and duration. Specifically, joint work and duration was compared between and within exercises (HPC and JS), load (30, 50, and 70% 1RM HPC), and joint (hip, knee, and ankle). Two-way interaction effects were examined using pooled (i.e., average) data across whichever variable was not part of the interaction (e.g., for the exercise × joint interaction, global measures of dependent variables were calculated by averaging across all loads). If the assumption of sphericity was violated, Greenhouse-Geisser adjusted values were used. The normality and homogeneity of the variance were examined using the Shapiro-Wilk and Levene's tests, respectively, before data were compared. Statistical significance for all analyses was set at a level of $\alpha = 0.05$. In addition, Cohen's *d* effect sizes, statistical power (*c*), and 95% confidence intervals (CIs) are presented. All statistical analyses were performed using SPSS 24 (IBM Corp., Armonk, NY, USA).

Results

Two participants were identified as outliers and were removed from the statistical analyses. The Shapiro-Wilk results indicated that all data were normally distributed. The Levene's tests were not statistically significant and thus, equal variances were assumed. The reliability statistics for relative joint work and loading duration are displayed in Tables 1 and 2, respectively.

Table 1. - Intraclass correlation coefficient reliability results for relative joint work.*

Joint	Hang power clean			Jump shrug		
	30%	50%	70%	30%	50%	70%
Hip	0.29	0.40	0.82	0.92	0.92	0.80
Knee	0.92	0.93	0.94	0.95	0.95	0.92
Ankle	0.78	0.59	0.80	0.94	0.80	0.88

*Percentages are based on the 1 repetition maximum hang power clean.

Table 2. - Intraclass correlation coefficient reliability results for loading duration.*

Joint	Hang power clean			Jump shrug		
	30%	50%	70%	30%	50%	70%
Hip	0.74	0.58	0.50	0.75	0.85	0.90
Knee	0.80	0.70	0.73	0.84	0.88	0.93
Ankle	0.71	0.75	0.81	0.87	0.93	0.93

*Percentages are based on the 1 repetition maximum hang power clean.

Relative Joint Work

The relative joint work descriptive statistics are displayed in Table 3. Statistically significant main effect differences in joint work existed for exercise ($F_{1, 10} = 45.068, p < 0.001, c = 1.00$), load ($F_{2, 20} = 12.965, p < 0.001, c = 0.99$), and joint ($F_{1.25, 12.497} = 75.214, p < 0.001, c = 1.00$). In addition, statistically significant exercise × joint ($F_{2, 20} = 47.255, p < 0.001, c = 1.00$) and load × joint ($F_{4, 40} = 10.961, p < 0.001, c = 1.00$) interaction effects were present. Finally, there was no statistically significant exercise × load ($F_{2, 20} = 2.576, p = 0.101, c = 0.454$) or exercise × load × joint ($F_{1.716, 17.156} = 2.025, p = 0.166, c = 0.554$) interaction effects present. Post hoc analyses indicated that the JS was characterized by greater load-averaged joint work compared with the HPC

performed at the hip ($p < 0.001$, $d = 0.84$, $CI = 0.10-0.23$), knee ($p < 0.001$, $d = 1.85$, $CI = 0.48-0.66$), and ankle joints ($p < 0.001$, $d = 1.49$, $CI = 0.08-0.13$; Figure 3). In addition, greater joint-averaged joint work was performed during the JS compared with the HPC performed at 30% ($p < 0.001$, $d = 0.89$, $CI = 0.20-0.42$), 50% ($p < 0.001$, $d = 0.74$, $CI = 0.17-0.37$), and 70% 1RM HPC ($p < 0.001$, $d = 0.66$, $CI = 0.17-0.34$; Figure 4).

Table 3. - Descriptive relative joint work (Joules per kilogram) statistics for the hang power clean and jump shrug performed at 30, 50, and 70% of 1 repetition maximum.*

Joint	Hang power clean			Jump shrug		
	30%	50%	70%	30%	50%	70%
Hip	0.56 ± 0.09	0.71 ± 0.15	0.84 ± 0.14	0.76 ± 0.21	0.87 ± 0.22	0.99 ± 0.21
Knee	0.44 ± 0.29	0.53 ± 0.25	0.56 ± 0.25	1.09 ± 0.37	1.08 ± 0.35	1.07 ± 0.36
Ankle	0.14 ± 0.05	0.14 ± 0.04	0.14 ± 0.04	0.23 ± 0.10	0.25 ± 0.10	0.25 ± 0.07

*Percentages are based on the 1 repetition maximum hang power clean.

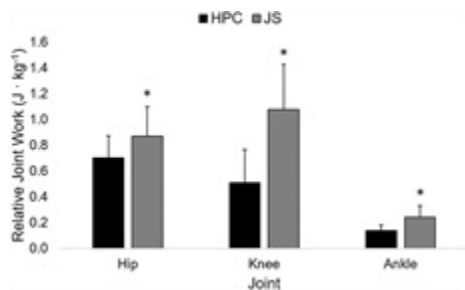


Figure 3.: Load-averaged relative joint work performed at the hip, knee, and ankle joints during the hang power clean (HPC) and jump shrug (JS). *Statistically greater than HPC ($p < 0.001$).

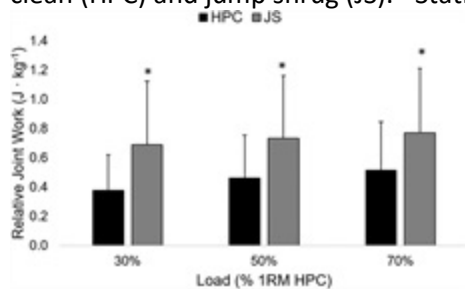


Figure 4.: Joint-averaged relative joint work performed during the hang power clean (HPC) and jump shrug (JS) performed at 30, 50, and 70% 1RM HPC. *Statistically greater than HPC ($p < 0.001$). 1RM = 1 repetition maximum.

Loading Duration

The loading duration descriptive statistics are displayed in Table 4. Statistically significant main effect differences in loading duration existed for exercise ($F_{1,10} = 20.767$, $p = 0.001$, $c = 0.983$), load ($F_{2,20} = 4.925$, $p = 0.018$, $c = 0.74$), and joint ($F_{1.15,11.452} = 122.214$, $p < 0.001$, $c = 1.00$). In addition, statistically significant exercise × joint ($F_{2,20} = 10.080$, $p = 0.001$, $c = 0.969$) and load × joint ($F_{4,40} = 3.506$, $p = 0.015$, $c = 0.819$) interaction effects were present. Finally, there was no statistically significant exercise × load ($F_{1.34,13.38} = 0.086$, $p = 0.918$, $c = 0.059$) or exercise × load × joint ($F_{4,40} = 1.120$, $p = 0.360$, $c = 0.319$) interaction effects present. Post hoc analyses indicated that the JS had a longer load-averaged loading duration compared with the HPC performed at the hip ($p < 0.001$, $d = 0.94$, $CI = 0.06-0.13$), knee ($p = 0.001$, $d = 0.89$, $CI = 0.08-0.15$), and ankle joints ($p < 0.001$, $d = 0.99$, $CI = 0.10-0.18$; Figure 5). In addition, the JS had a longer joint-averaged loading duration compared with the HPC performed at 30% ($p < 0.001$, $d = 0.83$, $CI = 0.08-0.15$), 50% ($p < 0.001$, $d = 0.79$, $CI = 0.08-0.17$), and 70% 1RM HPC ($p < 0.001$, $d = 0.85$, $CI = 0.08-0.14$; Figure 6).

Table 4. - Descriptive loading duration (seconds) statistics for the hang power clean and jump shrug performed at 30, 50, and 70% of 1 repetition maximum.*

Joint	Hang power clean			Jump shrug		
	30%	50%	70%	30%	50%	70%
Hip	0.45 ± 0.10	0.45 ± 0.12	0.49 ± 0.07	0.55 ± 0.11	0.56 ± 0.11	0.58 ± 0.10
Knee	0.57 ± 0.13	0.59 ± 0.15	0.65 ± 0.08	0.70 ± 0.14	0.70 ± 0.14	0.76 ± 0.12
Ankle	0.58 ± 0.14	0.57 ± 0.19	0.63 ± 0.10	0.71 ± 0.14	0.72 ± 0.15	0.76 ± 0.12

*Percentages are based on the 1 repetition maximum hang power clean.

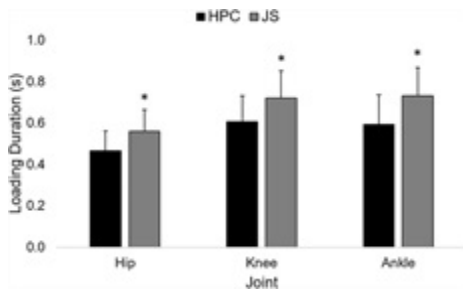


Figure 5.: Load-averaged loading duration at the hip, knee, and ankle joints during the hang power clean (HPC) and jump shrug (JS). *Statistically greater than HPC ($p < 0.01$).

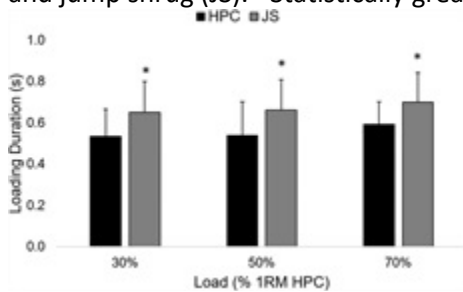


Figure 6.: Joint-averaged loading duration of the hang power clean (HPC) and jump shrug (JS) performed at 30, 50, and 70% 1RM HPC. *Statistically greater than HPC ($p < 0.001$). 1RM = 1 repetition maximum.

Discussion

This study compared the joint work and duration of the load absorption phase of a weightlifting catching derivative (i.e., HPC) and a weightlifting pulling derivative (i.e., JS). The primary findings are as follows: (a) Greater hip, knee, and ankle joint work was performed during the JS compared with the HPC when averaged across joints and loads, which was characterized by longer loading durations, and (b) As the external load increased, greater joint work was performed at each joint, while loading duration was maintained or increased.

Previous research indicated that the load absorption phase of the HPC and power clean mimicked joint work demands during jump and drop landings and may thus be used to train landing movements⁽²³⁾. It is commonly believed that the catch phase contributes to the load absorption experienced during weightlifting movements; however, recent research indicated that the load absorption work performed during several different weightlifting pulling derivatives that removed the catch phase was similar⁽¹¹⁾ or greater^(11,31) than weightlifting catching derivatives. The results of this study support the latter findings. The JS required the participants to perform more hip, knee, and ankle joint work during the load absorption phase compared to the HPC with moderate-large effect sizes being present when joint work was averaged across loads. Considering the movement demands of each exercise, these results should not be overly surprising. For example, athletes should be coached to “jump as high as possible” during the JS⁽³⁰⁾. As displayed by previous research⁽³¹⁾, a maximal jump during the JS may increase the eccentric forces experienced by the athlete on landing. Greater landing

forces, combined with a longer load absorption duration as shown in this study, may ultimately contribute to a greater amount of work performed by the athlete to decelerate their body mass and the external load. By contrast, athletes may be cued to aggressively extend their hip, knee, and ankle joints during the second pull phase to accelerate the barbell upward during the HPC. In addition, athletes may perform a small hop while moving their feet laterally to form a wider base of support (similar to a front squat) in preparation to catch the weight. Although racking the barbell across the shoulders during the catch phase may contribute to force absorption ⁽²³⁾, it should be noted that a properly executed HPC is characterized by catching the barbell near the top of its vertical path. This in turn may limit the downward displacement and kinetic energy of the barbell, ultimately decreasing the deceleration demand of the catch phase. The current results, as well as previous studies ^(11,31), support this notion.

Another interesting finding of the current study was focused on how the external load affected the joint work performed during the HPC and JS. Statistically greater joint work, with moderate practical effects, was performed during the load absorption phase of the JS compared with the HPC at each load examined. These findings are similar to those of Suchomel et al. ⁽³¹⁾, who reported that athletes may perform as much as 3–6× the amount of work during the load absorption phase of the JS compared with the HPC. However, it should be noted that in the previous study, and the current study, the differences in the load absorption work or joint work performed became smaller as the external load increased. Although moderate effect sizes still existed, the difference in the joint work performed during the JS and HPC was the smallest at the highest load examined (e.g., 70% 1RM HPC). Considering the technique of each exercise, a deeper squat may have been required to properly execute the catch phase of the HPC at 70% 1RM, which would ultimately result in more overall work performed. Practically speaking, these data support previous recommendations for the use of heavier loads with the HPC ^(20,21,26). Although joint work may increase with heavier loads during the JS as well, athletes may benefit more from using lighter loads with the JS due to its ballistic nature and force-time characteristics ^(22,25,31–36).

As noted above, the HPC and JS techniques differ in how the load absorption phase is performed. For example, Suchomel et al. ⁽³¹⁾ indicated that weightlifting derivatives may possess a unique load absorption profile (e.g., high mean forces and short loading duration vs. low mean forces and longer loading duration). The catch phase of the HPC resembles a front squat, although the HPC catch is typically performed using a semisquat (above parallel depth). The JS, by contrast, requires the athlete to land in the midhigh position ⁽¹⁵⁾ with their feet approximately shoulder-width apart and an upright torso. A benefit of landing in this manner is that the midhigh position is considered the strongest position within weightlifting movements ⁽¹⁶⁾. Because the HPC and JS both require an athlete's torso be in an upright position during their respective load absorption phases, both exercises may benefit athletes from a joint load absorption standpoint in the vertical plane. Furthermore, given their unique loading profiles, these exercises may be best implemented during different phases of training to match specific resistance training goals.

A limitation to the current study may be use of loads based off of the 1RM HPC. However, as previous literature has noted, there is no criteria for performing a 1RM weightlifting pulling derivative ⁽²⁹⁾ and thus, attempting to do so may be inappropriate. Future research may consider using percentages of bodyweight or comparing the bar velocity between weightlifting catching and pulling derivatives to determine what relative loads are comparable. The authors acknowledge that load absorption joint power was not included in the current analysis. This may be viewed as a limitation to the current study; however, it should be noted that several joint and load combinations were unreliable based on test-retest statistics. The rate of work performed during the load absorption phase of weightlifting catching and pulling derivatives at the hip, knee, and ankle joints (i.e., joint power) may be something that future research should investigate to determine if any differences exist. However, it should be noted that those interested in performing this research will have to be explicit when providing load absorption phase cues to ensure that a consistent technique is used.

Practical Applications

The JS required greater hip, knee, and ankle joint work performed over longer loading durations on landing compared with the load absorption phase of the HPC at each load examined. Thus, the JS may be used as an effective alternative to the HPC for load absorption benefits. However, the HPC and JS may provide unique load absorption training benefits based on how they load the hip, knee, and ankle joints. Practitioners should also note that the external load used during the HPC and JS does not seem to alter the joint work performed during the load absorption phase. Therefore, both exercises may be prescribed for load absorption benefits; however, it is important to consider the goals of each training phase. Based on the performance benefits, force-velocity characteristics, and load absorption benefits, the HPC may be best implemented during a maximal strength phase with moderate-heavy loads. By contrast, the JS may be best implemented during a speed-strength phase with light-moderate loads.

Practitioners should note that a properly executed catch phase (i.e., athlete meets the barbell near its maximum height) may limit the deceleration demand of the HPC and thus, decrease the load absorption stimulus. Although some load absorption benefits may occur, the current study, along with previous research (^{11,31}), indicates that the catch phase of the HPC may not be an optimal method to train deceleration. For example, as athletes continue to train with weightlifting catching derivatives, it is possible that they may begin to experience less of a force absorption requirement as the result of refined exercise technique. However, further research is needed to compare the load absorption demands of weightlifting catching and pulling derivatives as well as other resistance training exercises (e.g., squat variations, jump squats, etc.). Moreover, additional research is needed to determine how technique changes affect load absorption during a weightlifting catching derivative.

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