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Load absorption force-time characteristics following the second pull of weightlifting derivatives

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ABSTRACT

The purpose of this study was to compare the load absorption force-time characteristics of weightlifting catching and pulling derivatives. Twelve resistance-trained men performed repetitions of the hang power clean (HPC), jump shrug (JS), and hang high pull (HHP) on a force platform with 30, 45, 65, and 80% of their one repetition maximum (1RM) HPC. Load absorption phase duration, mean force, and work were calculated from the force-time data. The HHP produced a significantly longer load absorption phase duration compared to the HPC ($p < 0.001$, $d = 3.77$) and JS ($p < 0.001$, $d = 5.48$), while no difference existed between the HPC and JS ($p = 0.573$, $d = 0.51$). The JS produced significantly greater load absorption mean forces compared to the HPC ($p < 0.001$, $d = 2.85$) and HHP ($p < 0.001$, $d = 3.75$), while no difference existed between the HPC and HHP ($p = 0.253$, $d = 0.37$). Significantly more load absorption work was performed during the JS compared to the HPC ($p < 0.001$, $d = 5.03$) and HHP ($p < 0.001$, $d = 1.69$), while HHP load absorption work was also significantly greater compared to the HPC ($p < 0.001$, $d = 4.81$). The weightlifting pulling derivatives examined in the current study (JS and HHP) produced greater load absorption demands following the second pull compared to the weightlifting catching derivative (HPC). The JS and HHP may be used as effective training stimuli for load absorption during impact tasks such as jumping.

Key Words: hang power clean, jump shrug, hang high pull, eccentric loading, catch phase

INTRODUCTION

Implementing weightlifting movements and their derivatives into strength and conditioning programs has become increasingly popular. This is likely due to the superior training adaptations (strength, vertical jump height, sprint speed, etc.) that result from their inclusion compared to other training methods (10, 17, 31). _ENREF_2Most of the research that has examined weightlifting derivatives has investigated the kinetic and kinematic characteristics of the second pull (2-5, 19-21, 29, 30). This is not surprising given that the second pull phase of the clean and snatch, which is characterized by the triple extension of the hips, knees, and ankles (plantar flexion) and the shrugging of the shoulders, results in the greatest production of force and power (6-8), and transfers to sport tasks with similar joint movements (22). While this information is important for exercise prescription, less is known about the force-time characteristics following the second pull. If additional benefits could be obtained from weightlifting derivatives in the form of the mechanical demands made following the second pull, indicated by the force-time characteristics, an even stronger case could be made for the inclusion of weightlifting derivatives into resistance training programs of sports/events that do not typically use them.

A purported benefit of weightlifting derivatives that involve the completion of the catch phase is the ability to train the individual to “accept”, “decelerate”, or “absorb” a load (22). Furthermore, although not supported by evidence, some may believe that the catching action may simulate receiving an impact in sports such as American football or rugby. Research by Moolyk and colleagues (14) examined strategies used to absorb force during a jump landing, a drop landing, a clean (i.e. squat/full clean), and a power clean (i.e. clean caught in a semi-squat position). Their results indicated that the clean resulted in more overall joint work compared to the power clean, but was not different from the drop landing. They concluded that the clean and power clean could be used to train the muscular strength required for impact actions, such as jump landing. While the previous study examined the load absorption differences between two weightlifting movements that involved the catch phase, no research has compared the load absorption phase of weightlifting catching derivatives and weightlifting pulling derivatives that exclude the catch phase.

Previous research has indicated that the weightlifting pulling derivatives that omit the catch phase may produce similar (i.e. small-moderate effect sizes) (2, 3) or superior (i.e. large-very large effect sizes) (27, 29, 30) force and power characteristics compared to weightlifting catching derivatives. Moreover, several weightlifting pulling derivatives may allow an individual to train with loads that are greater than the maximum weight lifted during a catching derivative (4, 5, 9, 12), which may emphasize force production. As a result, practitioners may consider implementing weightlifting pulling derivatives as a substitute to the clean or snatch, or as an additional exercise to train triple extension (22, 26)._ENREF_1 Due to the potential training benefits of weightlifting pulling derivatives during the concentric phase (i.e. force production and external power characteristics) (2, 3, 27, 29, 30), further research is needed to examine their force-time characteristics following the second pull to determine if they provide an eccentric loading stimulus similar to traditional weightlifting exercises. Previous research that examined post-second pull force-time characteristics of the jump shrug (JS) indicated that landing forces decreased as the external load increased (28). While this information is beneficial to practitioners who may question the mechanical consequences of the JS landing, further research is needed to understand force-time characteristics following the second pull of the JS, as well as other weightlifting catching and pulling derivatives. Comparisons of the load absorption force-time characteristics following the second pull of weightlifting catching and pulling derivatives may be beneficial from a programming standpoint for those interested in implementing weightlifting derivatives to train both the concentric and eccentric phases of the lift. Therefore, the purpose of this study was to compare the load absorption force-time characteristics of the hang power clean (HPC) catch phase, JS landing phase, and hang high pull (HHP) landing phase. It was hypothesized that the JS would produce the greatest load absorption demands due to the landing characteristics associated with the exercise (28).

METHODS

Experimental Approach to the Problem

A repeated measures design was used to compare the load absorption force-time characteristics following the second pull phase of the HPC, JS, and HHP. Subjects performed sets of the HPC, JS, and HHP with 30, 45, 65, and 80% of their one repetition maximum (1RM) HPC. Load absorption phase work, mean force, and duration were calculated from the force-time data and compared to quantify between-exercise differences. The work performed during the load absorption phase was studied to establish the effect that exercise and load had on the absorption of potential energy during the loading phase following the second pull of each movement. Mean force during the load absorption phase was examined as opposed to peak force to provide a greater understanding of the magnitude of force produced over the duration of the loading phase of each weightlifting derivative. Finally, load absorption duration was studied to examine the length of time over which force was produced in order to decelerate the system center of mass during each weightlifting derivative.

Subjects

Twelve resistance-trained men participated in this study (age = 21.4 ± 1.2 years, height = 180.3 ± 6.2 cm, body mass = 83.2 ± 8.4 kg, 1RM HPC = 108.5 ± 14.6 kg, relative 1RM HPC = 1.3 ± 0.2 $kg \cdot kg^{-1}$). All of the subjects participated in NCAA Division III track and field (short sprints, jumps, or throws) or collegiate club/intramural sports and had at least two years of training experience with weightlifting derivatives. Each subject read and signed a written informed consent form. The current study was approved by the University's Institutional Review Board. Twelve subjects were recruited based on an *a priori* power analysis that indicated that 12-14 subjects would be needed to establish a moderate effect (Cohen's d = 0.60) (11) at a statistical power level of 0.80.

Procedures

All subjects attended four sessions that included a 1RM testing and practice session and three subsequent exercise testing sessions. Each session was carried out at the same time of day (2-7 days apart) with the subjects refraining from physical activity that could affect their performance at least 24 hours before each testing session.

Upon arrival for the 1RM testing and practice session, subjects completed a standardized dynamic warm-up and submaximal HPC sets before making 1RM attempts, following a previously described protocol (20, 29). Briefly, subjects attempted progressively heavier loads (minimum 2.5 kg increase) until a failed attempt occurred. The largest successfully lifted load was recorded as each subject's 1RM. All HPC repetitions were performed using previously described technique (20) and repetitions caught in a squat position where the upper thigh of the subject was below parallel to the floor were considered unsuccessful. Following a self-selected rest period, subjects practiced the JS and HHP and were coached on proper technique. Specifically, each subject performed submaximal sets of the JS and HHP using 30% of their 1RM HPC in accordance with previous research (29). All JS and HHP repetitions were completed using the technique previously described by Suchomel and colleagues (23, 24). It should be noted that a 1RM JS and HHP were not performed as no criteria exist on what constitutes a successful 1RM attempt of weightlifting pulling derivatives (25).

The order of the remaining exercise testing sessions was randomized. Prior to testing, each subject performed the same dynamic warm-up as previously described followed by submaximal sets (i.e. one set of three repetitions with 30 and 50% 1RM HPC) of the exercise that was to be tested during that session (HPC, JS, or HHP). To clarify, if the subjects were going to test the JS during that particular testing session, they would perform a set of three JS repetitions with 30 and 50% of their 1RM HPC as part of their warm-up before performing testing repetitions. Following the warm-up, subjects performed two maximal effort repetitions of the testing session exercise with 30, 45, 65, and 80% of their 1RM HPC on a force platform (Kistler, Type 9290AD, Kistler, Winterthur, Switzerland) sampling at 500 Hz with one minute of rest between repetitions and two minutes between loads. It should be noted that no additional instructions were given to the subjects prior to or after each repetition regarding their landing technique as extra instruction or feedback may impact the ground reaction forces produced (13, 15, 16). The order of loads was randomized in an attempt to prevent a fatigue or potentiation order effect during the first testing session. The same randomized order of loads was used during each subsequent testing session with the remaining exercises. Subjects rested for one minute between repetitions and two minutes between loads.

Data Analyses

Force-time data were exported from Bioware and analyzed using a custom LabVIEW program (Version 10.0; National Instruments, Austin, TX, USA). Force-time data from each repetition were analyzed to obtain load absorption phase work, mean force, and duration after completion of the second pull phase. The transition from pulling to load absorption was represented by two distinct force-time curves (Figures 1, 2, and 3); the most obvious where subjects left the ground (JS and HPC, Figures 1 and 2), and when this occurred a force threshold of 10 N was used to indicate both take off and load absorption in accordance with previous work by Owen et al (18). In the event that the subjects did not leave the ground (e.g. HHP), the lowest post-pull force was identified and the same 10 N threshold used to identify the beginning of load absorption (lowest force + 10 N, Figure 3). The load absorption phase ended when the system (lifter plus bar) center of mass reached its lowest post landing displacement (See Figures 1-3). Acceleration-time data were calculated by dividing net force by system mass, and this was integrated with respect to time using the trapezoid rule to first yield velocity-time data, and then again to yield displacement-time data. Mean force was calculated by averaging the force produced over the duration of the load absorption phase. The displacement of the system center of mass was calculated by subtracting the position of the system center of mass at the end of the load absorption phase from its position at the beginning of the phase. Work was then calculated as the product of the mean force and displacement. The load absorption phase work, mean force, and duration of each HPC, JS, and HHP repetition was used to assess trial-to-trial reliability and then averaged for further statistical analyses.

(Figures 1-3 about here.)

Statistical Analyses

Intraclass correlation coefficients (ICC: 3,1) were used to determine the test-retest reliability of load absorption phase work, mean force, and duration based on the recommendations from Weir (33). The normality of the data distribution was tested by using the Shapiro-Wilks test. To compare the differences in load absorption phase work, mean force, and duration between the HPC, JS, and HHP, a series of 3 x 4 (exercise x load) repeated measures ANOVAs were used. If the assumption of sphericity was violated, Greenhouse-Geisser adjusted values were reported. When appropriate, *post hoc* analysis was performed applying the Bonferroni correction. The alpha value was set at ≤ 0.05 for all statistical measures. Statistical power (*c*) was calculated for all main effect comparisons. In addition, Cohen's *d* effect sizes and 95% confidence intervals (CI) were calculated for all pairwise comparisons. Effect sizes were interpreted as trivial, small, moderate, large, very large, and nearly perfect if values were equal to 0.00-0.19, 0.20-0.59, 0.60-1.19, 1.20-1.99, 2.00-3.99, and 4.00 or greater, respectively (11). All statistical analyses were performed using SPSS 22 (IBM, Armonk, NY, USA).

RESULTS

The ICC statistics for load absorption phase work, mean force, and duration during the HPC, JS, and HHP are displayed in Table 1.

(Table 1 about here.)

Significant exercise ($F_{2,22} = 154.598$, $p < 0.001$, $c = 1.00$), load ($F_{1.54,16.88} = 17.947$, $p < 0.001$, $c = 0.99$) and exercise x load interaction ($F_{6,66} = 7.027$, $p = 0.001$, $c = 0.97$) effects existed for load absorption work. *Post hoc* analysis revealed that significantly more load-averaged work was performed during the JS (647.3 ± 111.1 J) compared to the HPC (129.9 ± 93.7 J; $p < 0.001$, $d = 5.03$, CI = 415.6 – 619.4) and HHP (448.8 ± 123.4 J; $p < 0.001$, $d = 1.69$, CI = 147.5 – 249.5). In addition, significantly more load-averaged work was performed during the HHP compared to the HPC ($p < 0.001$, $d = 4.81$, CI = 229.2 – 408.7) (Figure 4).

Post hoc analysis revealed that significantly more exercise-averaged work was performed with 80% 1RM (451.5 ± 229.6 J) compared to 30% (366.8 ± 229.1 J; $p = 0.001$, $d = 0.37$, CI = 33.9 – 135.5), 45% (406.0 ± 253.7 J; $p = 0.033$, $d = 0.19$, CI = 3.0 – 88.0), and 65% 1RM (410.3 ± 250.0 J; $p = 0.001$, $d = 0.17$, CI = 17.1 – 65.3). In addition, the work performed with 65% 1RM was significantly greater than work with 30% 1RM ($p = 0.035$, $d = 0.18$, CI = 2.6 – 84.4), but was not different than 45% 1RM (*p* = 0.011, *d* = 0.02, CI = -29.6 – 38.1). Finally, the work performed with 45% 1RM was significantly greater than work with 30% 1RM (*p* = 0.001, *d* = 0.16, CI = 17.6 – 60.9) (Figure 4).

(Figure 4 about here.)

The HPC, JS, and HHP exercise and load interaction for load absorption work is displayed in Figure 5.

(Figure 5 about here.)

Significant exercise ($F_{1.23,13.48}$ = 89.575, *p* < 0.001, *c* = 1.00), load ($F_{1.63,17.97}$ = 21.734, *p* < 0.001, *c* = 1.00) and exercise x load interaction ($F_{6,66}$ = 7.038, *p* < 0.001, *c* = 0.99) effects existed for load absorption mean force. *Post hoc* analysis revealed that the load-averaged mean force for the JS (2674.1 ± 420.6 N) was significantly greater compared to the HPC (1488.1 ± 411.6 N; *p* < 0.001, *d* = 2.85, CI = 782.3 – 1589.7) and HHP (1359.6 ± 259.9 N; *p* < 0.001, *d* = 3.75, CI = 1031.1 – 1597.9), while the HPC and HHP were not significantly different (*p* = 0.253, *d* = 0.37, CI = -62.5 – 319.4) (Figure 6).

Post hoc analysis revealed that exercise-averaged mean forces with 80% (2061.6 ± 629.2 N) were significantly larger than mean forces with 30% (1683.7 ± 747.0 N; *p* = 0.002, *d* = 0.55, CI = 144.4 – 611.44), 45% (1751.2 ± 731.6 N; *p* = 0.001, *d* = 0.45, CI = 124.7 – 496.0), and 65% 1RM (1865.8 ± 650.1 N; *p* = 0.015, *d* = 0.31, CI = 33.8 – 357.7). In addition, mean forces with

65% 1RM were significantly larger than mean forces with 30% (p = 0.015, d = 0.26, CI = 32.2 – 332.2) and 45% 1RM (p = 0.011, d = 0.17, CI = 24.5 – 204.8). Mean forces with 30% and 45% 1RM were not significantly different (p = 0.297, d = 0.09, CI = -30.7 – 165.7) (Figure 6).

(Figure 6 about here.)

The HPC, JS, and HHP exercise and load interaction for load absorption mean force is displayed in Figure 7.

(Figure 7 about here.)

Significant exercise ($F_{2,22}$ = 126.694, $p < 0.001$, c = 1.00) and exercise x load interaction ($F_{3.02, 33.24}$ = 7.901, $p < 0.001$, c = 0.98) effects existed for load absorption phase duration; however no significant load main effects existed ($F_{1.78, 19.54}$ = 0.330, p = 0.698, c = 0.093). *Post hoc* analysis revealed that the load-averaged load absorption duration of the HHP (0.76 ± 0.13 s) was significantly longer compared to the HPC (0.27 ± 0.13 s; $p < 0.001$, d = 3.77, CI = 0.35 – 0.58) and JS (0.22 ± 0.05 s; $p < 0.001$, d = 5.48, CI = 0.43 – 0.60), while the HPC and JS were not significantly different (p = 0.573, d = 0.51, CI = -0.05 – 0.15) (Figure 8).

(Figure 8 about here.)

The HPC, JS, and HHP exercise and load interaction for load absorption duration is displayed in Figure 9.

(Figure 9 about here.)

DISCUSSION

This study compared the load absorption phase work, mean force, and duration differences of the HPC, JS, and HHP across a range of loads. The primary findings included 1) greater load absorption work was performed during the JS compared to the HPC and HHP, while greater work was also performed during the HHP compared to the HPC, 2) the JS produced greater load absorption mean forces compared to the HPC and HHP, and 3) the HHP produced a longer load absorption phase duration compared to the HPC and JS.

Because the work completed during the load absorption phase of weightlifting derivatives may improve an individual's capacity to absorb forces during impact tasks (14), examining the work completed during multiple derivatives may assist the practitioner in making programming decisions. The JS produced the largest magnitude of load absorption work compared to the HPC and HHP, with large practical effects being present. These findings are likely more attributed to the mean forces produced during the JS landing as opposed to the displacement. In contrast, the HHP produced the lowest magnitudes of mean force, but still achieved the second highest magnitude of work, resulting in large practical significance when compared to the HPC. It should be noted however that the barbell is traditionally caught before the barbell has any downward momentum by gravity during the HPC (32). As a result, the downward momentum to be absorbed during the HPC should be smaller than that of the JS and HHP. Our findings may have training implications, especially considering that the JS and HHP have previously been shown to produce superior performance characteristics during the second pull or propulsion phase compared to the HPC (27, 29, 30). Collectively, it appears that the JS and HHP may benefit both the concentric and eccentric phases of a weightlifting derivative to a similar or greater extent, compared to the HPC. From a loading perspective, the exercise-averaged work during the load absorption phase at 80% 1RM was the largest; however, it should be noted that only trivial-small effects were present between all the loads examined.

The largest load absorption phase mean forces were produced during the JS and were followed, in order, by the HPC and HHP. Large practical effects were present when comparing the JS and both the HPC and HHP, while only a small effect existed between the HPC and HHP. The JS is unique compared to the other weightlifting derivatives examined in the current study because it requires the individual to jump as high as possible (24). While this may enable high force, velocity, and power during the concentric phase (19, 29, 30), the results of this study suggest that the individual must absorb larger mean forces upon landing. This notion is supported by previous research that indicated that higher jump heights during the JS coincided with larger landing forces (28). Interestingly, the final load absorption phase deceleration position of the JS and HHP mimics the second pull position (i.e. mid-thigh position), which may enable the individual to effectively absorb forces in the strongest position that is achieved during weightlifting derivatives (6-8). While a purported benefit of a commonly prescribed weightlifting exercise (i.e. HPC) may be the rapid acceptance of an external load (22), our findings indicate that the JS may produce a greater training stimulus in this regard due to its shorter load absorption duration and larger mean forces. This suggests that the JS demands a greater eccentric rate of force development to decelerate an external load. Combining our findings with previous research, the JS may enable the individual to further develop the magnitude and rate of force production during both the concentric (27, 29) and eccentric phases (28) of the lift. However, practitioners should note the training phase in which the JS is implemented because repetitive high force eccentric loading, such as that produced during landing activities from maximal jumps, has been noted as a mechanism of delayed onset muscle soreness (1). Therefore, it is important to implement the JS, as well as other weightlifting derivatives, in a progressive manner to prevent an excessive volume of eccentric loading during training periods where the dissipation of accumulated fatigue is important (e.g. competition phase). Regarding the loads examined, the greatest load absorption mean forces were present with the highest load (i.e. 80% 1RM). However, it should be noted that the effect sizes that existed between all loads produced trivial-small magnitudes of practical significance, indicating that the external load does not appear to have much of an effect on load absorption mean forces. This is likely due to the interaction between decreased loads and increased displacements. For example, a greater displacement would provide additional time for gravitational acceleration, potentially resulting in a similar force required to decelerate the system mass.

This is the first study that has compared the load absorption phase duration of weightlifting derivatives. Interestingly, the HHP produced the longest load absorption duration compared to the HPC and JS (both large effects). These findings may be due to the required constraints of each exercise. As opposed to the JS, the HPC and HHP require the elevation of the barbell following the second pull (20, 23). While the barbell elevation is similar between these exercises, it is likely that individuals performing the HPC will only elevate the bar to a height where they can drop under the bar and rack it across their shoulders. In contrast, the HHP requires the individual to finish the movement with the barbell elevated to chest height while the triple extension of the hip, knee, and ankle (plantar flexion) joints is being completed (23). While this may emphasize the triple extension movement, it creates a larger displacement of the load and as a result, the individual must spend more time absorbing the external load as it is lowered from its maximum height and the bar returns to the mid-thigh position. The load absorption duration differences between the HPC and JS were not statistically significant (small effect). This may due to similar landing techniques as both the HPC and JS require the individual to land in a stiff semi-squat position to absorb the load as it either decelerates from its maximum height following the second pull (HPC) or as the center of mass decelerates as it lowers from peak jump height (JS). From a practical standpoint, our findings indicate that the HPC and JS appear to affect the magnitude and duration of landing force the individual is exposed to. In contrast, the HHP may facilitate greater absorption of forces during the load absorption phase compared to the HPC and JS. The latter findings indicate that the HHP may allow an individual to effectively dissipate the magnitude of force experienced following the second pull, potentially leading to a decreased accumulation of stress during multiple sets and repetitions.

A limitation of the current study may be the inclusion of load absorption phase variables only associated with the lifter plus bar system. While this limitation does not lessen the value of the results of the current study, future research should include the collection and analysis of three-dimensional kinetic and kinematic data to determine if similar trends exist at the joint level. The information within the current study combined with joint-level measurements may provide a better understanding of the similarities and differences between the load absorption phase of weightlifting catching and pulling derivatives. A second possible limitation to the current study was the exclusion of the lowering phase of the barbell during the HPC. If an athlete is performing multiple HPC repetitions, they must lower the barbell from a racked position across their shoulders to the mid-thigh position before the subsequent repetition. However, it should be noted that this may also be accomplished by dropping the barbell onto training blocks. While this may add to the overall work performed by the individual, the focus of the current study was to compare the catch phase of the HPC with the landing phases of the HHP and JS. Additional analyses were outside of the scope of this study.

PRACTICAL APPLICATIONS

Weightlifting pulling derivatives that exclude the catch phase may be used as effective training stimuli to improve force absorption following the second pull. Although a purported benefit of weightlifting catching derivatives is the rapid acceptance of an external load, the results of this study show that the exclusion of the catch does not diminish this effect, but rather increases it. The load absorption characteristics of each exercise may dictate what training phase may be the most appropriate. For example, the JS produced the greatest load absorption work and mean forces, while also producing the shortest load absorption phase duration. In order to prevent excessive eccentric loading from repetitive landing, but also effectively benefit from the JS's propulsion characteristics (19, 27, 29), the JS may be best implemented during a low volume, speed-strength training block. Finally, the external load prescribed does not appear to have much practical significance on the load absorption work, mean forces, or duration characteristics of the HPC, JS, or HHP. Therefore, practitioners may implement a variety of loads to train the load absorption characteristics of their athletes.

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TABLE AND FIGURE LEGENDS

Table 1. Reliability (ICC) of load absorption phase variables across exercises and loads.

Figure 1. Example hang power clean force-time and displacement-time curves. *Note*: *The shaded area denotes the load absorption phase duration*.

Figure 2. Example jump shrug force-time and displacement-time curves. *Note*: *The shaded area denotes the load absorption phase duration*.

Figure 3. Example hang high pull force-time and displacement-time curves. *Note*: *The shaded area denotes the load absorption phase duration*.

Figure 4. Load absorption work comparison between A) exercises and B) loads. * = statistically greater than the HPC ($p < 0.001$); # = statistically greater than the HHP ($p < 0.001$); a = statistically greater than 30% ($p < 0.05$); b = statistically greater than 45% ($p = 0.033$); c = statistically greater than 65% ($p = 0.001$)

Figure 5. Exercise and load interaction for load absorption work ($p = 0.001$). 1RM = one repetition maximum; HPC = hang power clean; JS = jump shrug; HHP = hang high pull.

Figure 6. Load absorption mean force comparison between A) exercises and B) loads. * = statistically greater than the HPC ($p < 0.001$); # = statistically greater than the HHP ($p < 0.001$); a = statistically greater than 30% ($p < 0.05$); b = statistically greater than 45% ($p < 0.05$); c = statistically greater than 65% ($p = 0.015$)

Figure 7. Exercise and load interaction for load absorption mean force ($p < 0.001$). 1RM = one repetition maximum; HPC = hang power clean; JS = jump shrug; HHP = hang high pull.

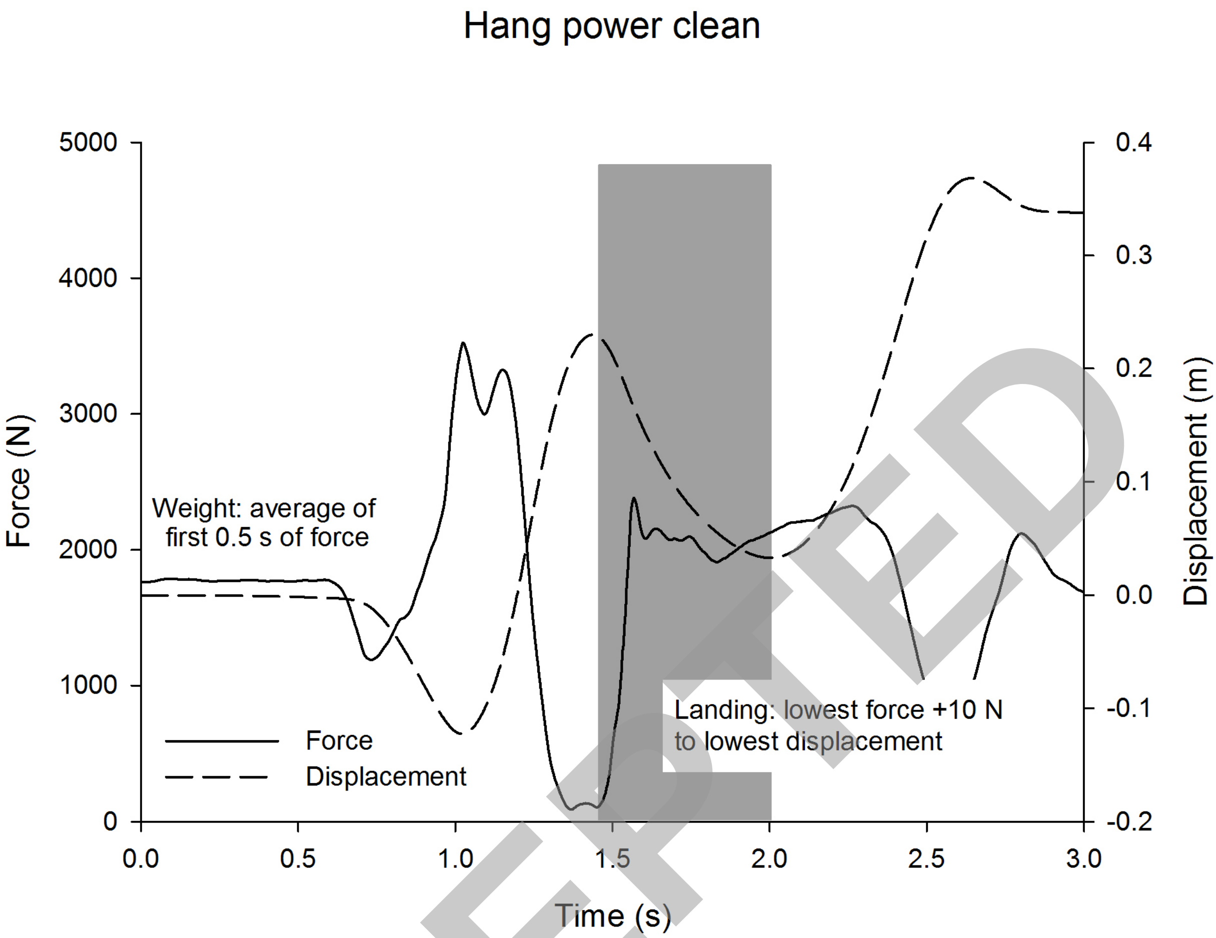
Figure 8. Load absorption duration comparison between A) exercises and B) loads. * = statistically greater than the HPC ($p < 0.001$); # = statistically greater than the JS ($p < 0.001$)

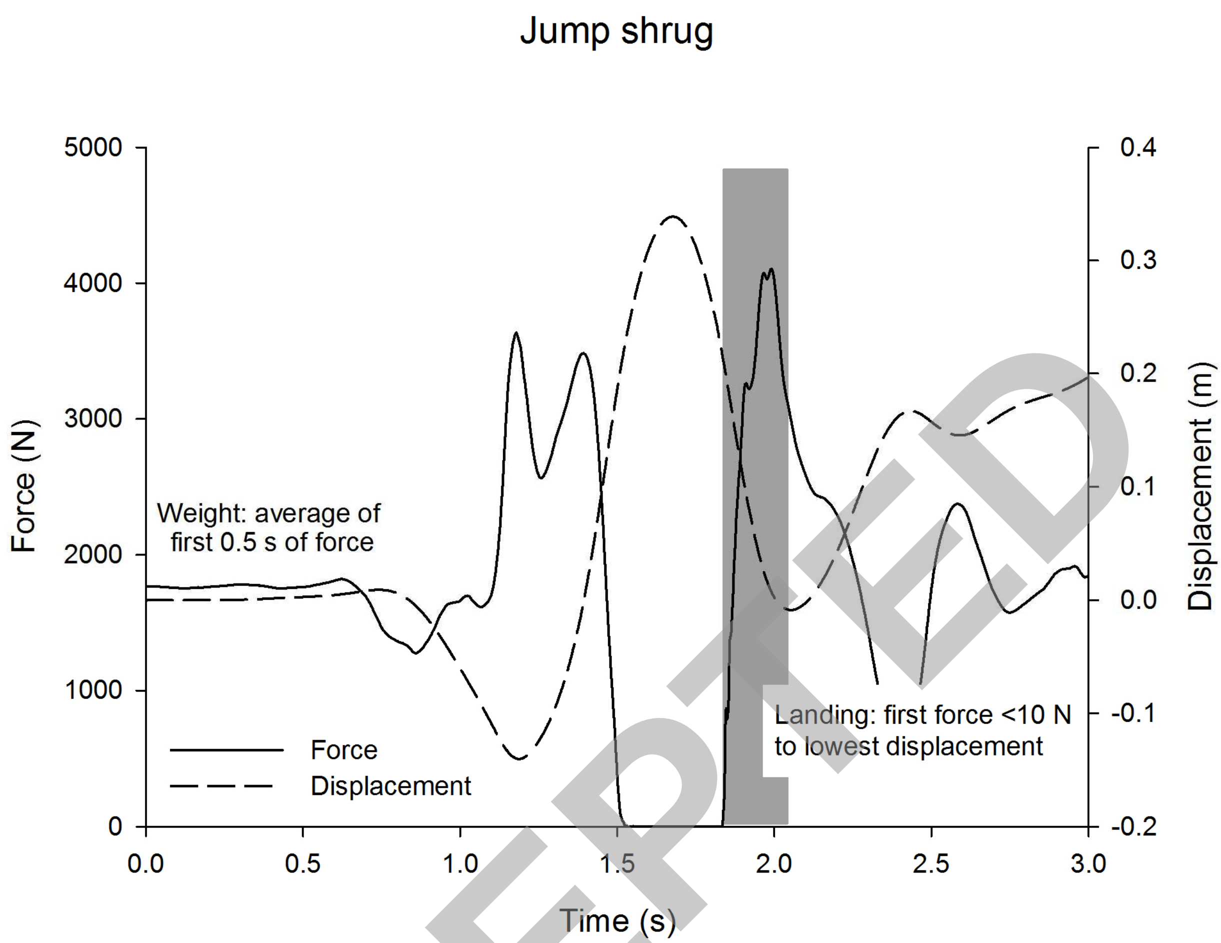
Figure 9. Exercise and load interaction for load absorption duration ($p < 0.001$). 1RM = one repetition maximum; HPC = hang power clean; JS = jump shrug; HHP = hang high pull.

Table 1. Reliability (ICC) of load absorption phase variables across exercises and loads.

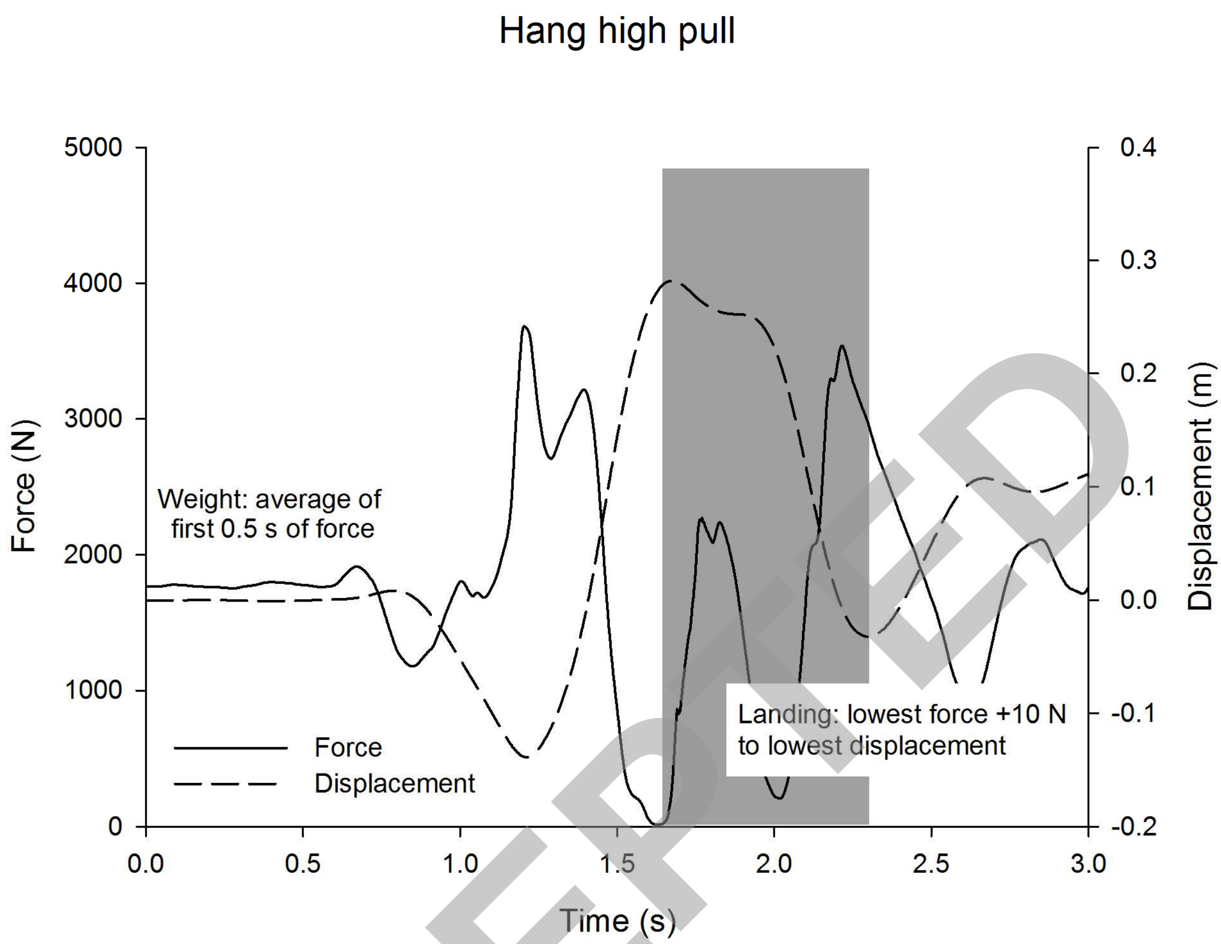
Exercise and Load (% 1RM HPC)	Load Absorption Work	Load Absorption Mean Force	Load Absorption Duration
HPC			
30%	0.97	0.98	0.96
45%	0.99	0.93	0.92
65%	0.99	0.96	0.98
80%	0.90	0.87	0.91
JS			
30%	0.94	0.91	0.79
45%	0.98	0.94	0.87
65%	0.98	0.96	0.94
80%	0.95	0.98	0.96
HHP			
30%	0.95	0.97	0.78
45%	0.94	0.96	0.96
65%	0.96	0.98	0.94
80%	0.96	0.98	0.85

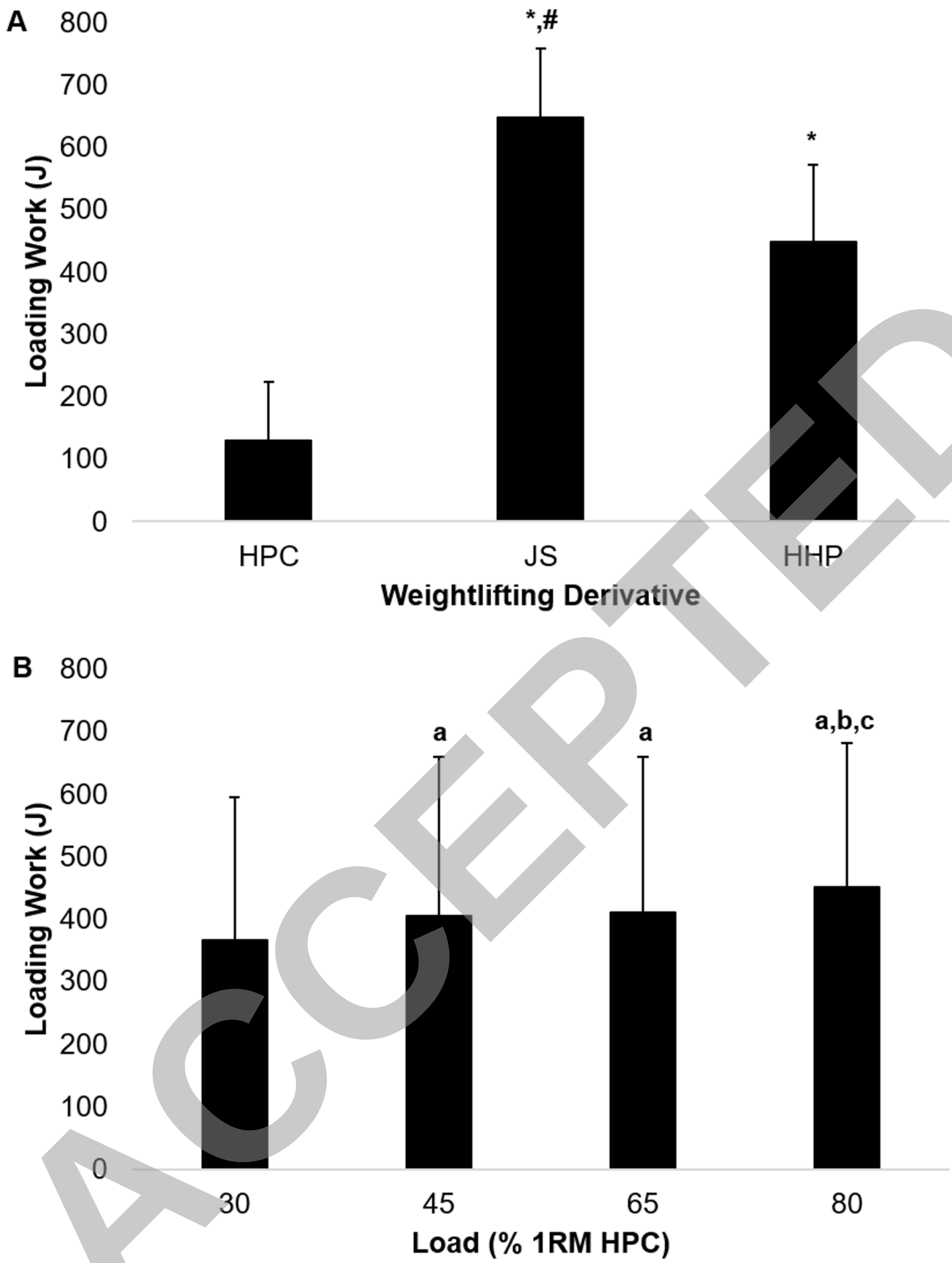
Notes: HPC = hang power clean; JS = jump shrug; HHP = hang high pull


Hang power clean
5000
4000
3000
2000
1000
0
Force (N)
0.4
0.3
0.2
0.1
0.0
-0.1
-0.2
Displacement (m)
0.0
0.5
1.0
1.5
2.0
2.5
3.0
Time (s)
Weight: average of
first 0.5 s of force
Landing: lowest force +10 N
to lowest displacement
Force
Displacement

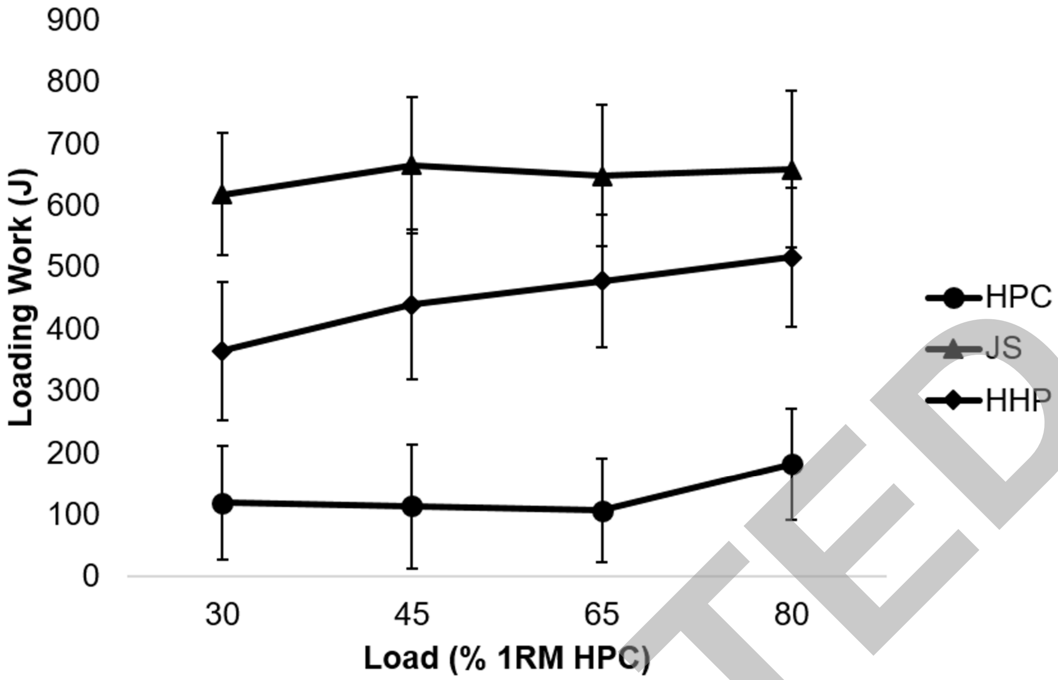


Jump shrug
5000
4000
3000
2000
1000
0
Force (N)
0.4
0.3
0.2
0.1
0.0
-0.1
-0.2
Displacement (m)
0.0
0.5
1.0
1.5
2.0
2.5
3.0
Time (s)
Weight: average of first 0.5 s of force
Landing: first force <10 N to lowest displacement
Force
Displacement

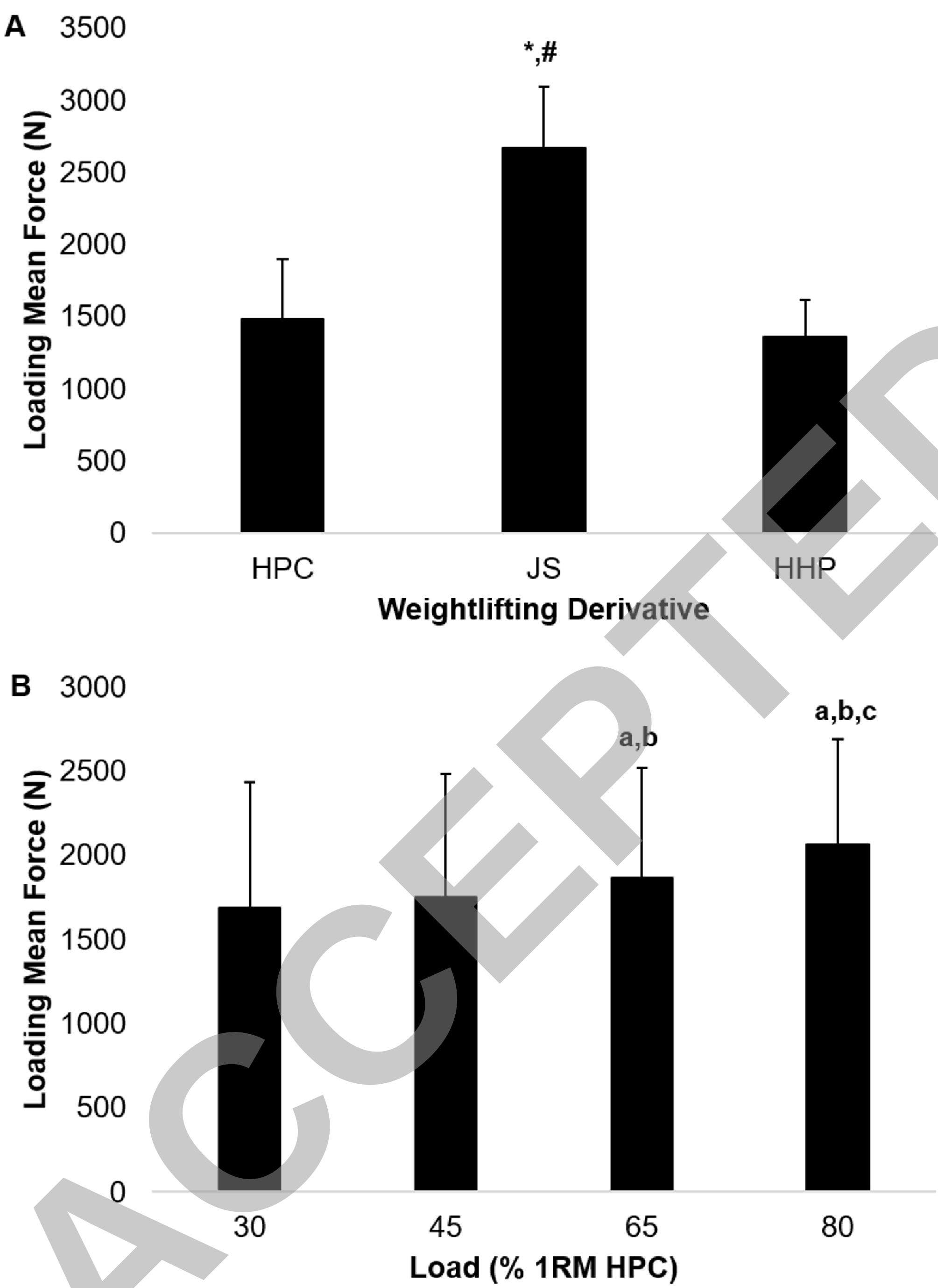

Hang high pull
Force (N)
Displacement (m)
Time (s)
5000
4000
3000
2000
1000
0
0.4
0.3
0.2
0.1
0.0
-0.1
-0.2
0.0
0.5
1.0
1.5
2.0
2.5
3.0
Weight: average of first 0.5 s of force
Landing: lowest force +10 N to lowest displacement
Force
Displacement

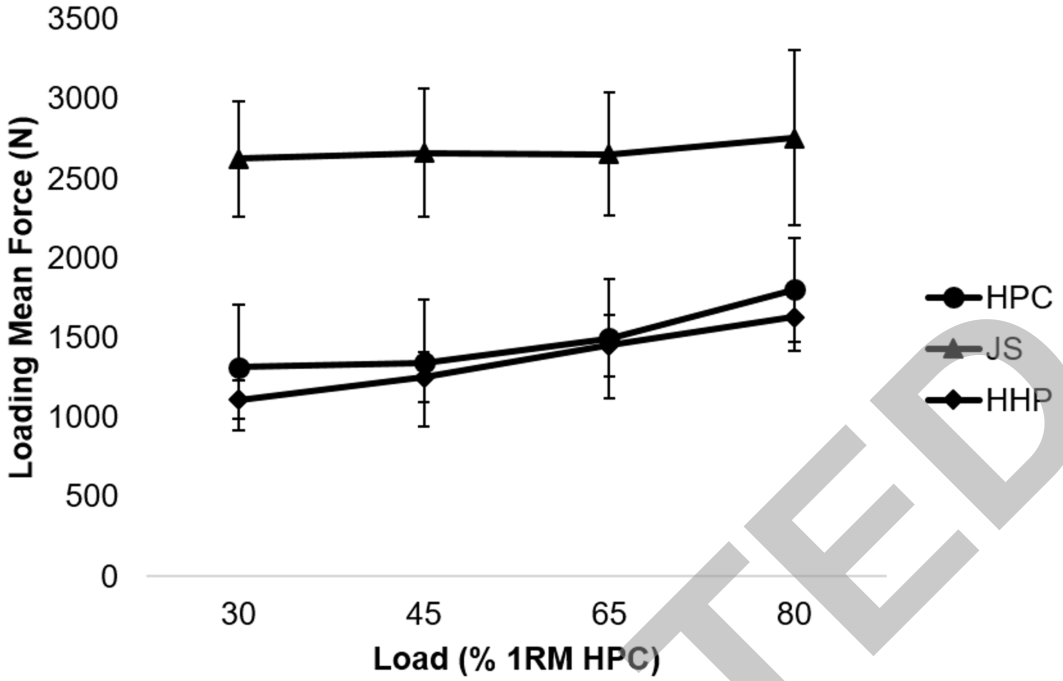


A
800
700
600
500
400
300
200
100
0
Loading Work (J)
*,#
*
HPC
JS
HHP
Weightlifting Derivative
B
Loading Work (J)
a
a
a,b,c
30
45
65
80
Load (% 1RM HPC)

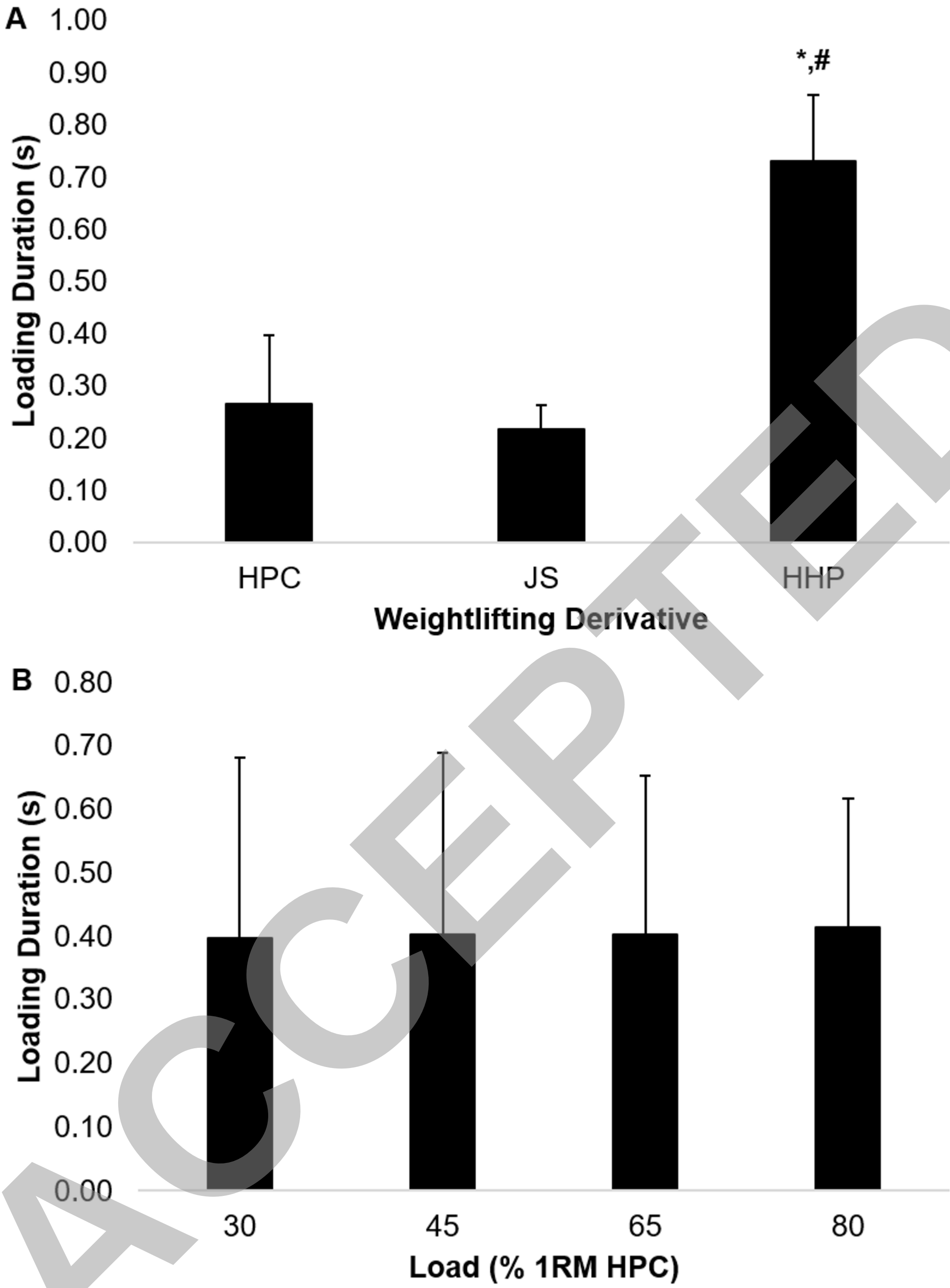


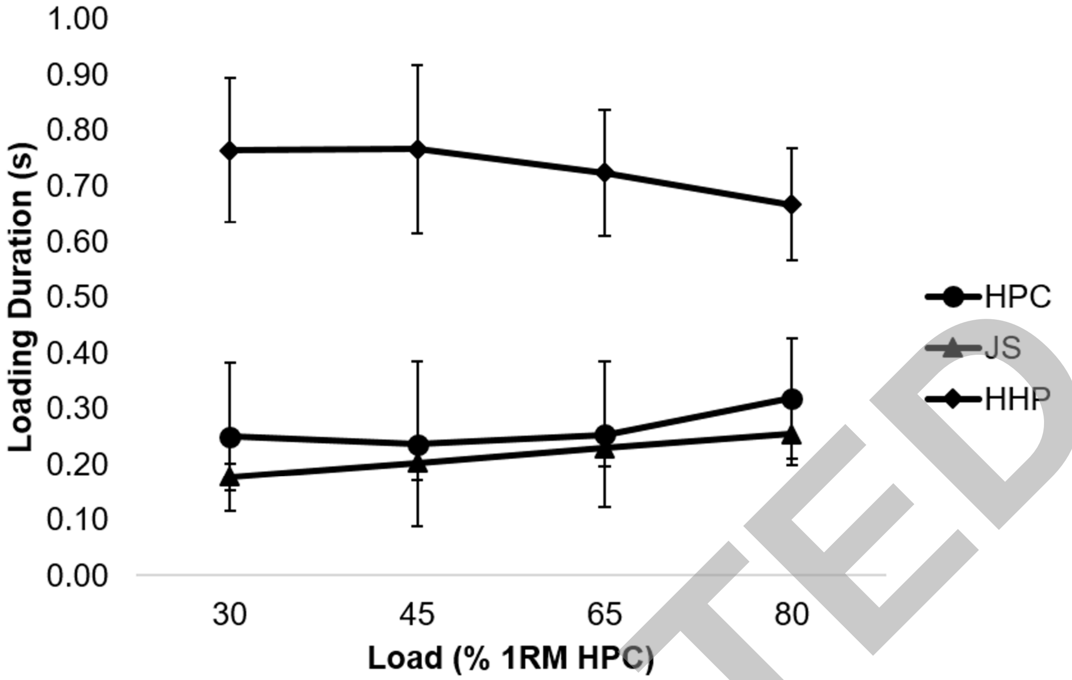
Loading Work (J)
900
800
700
600
500
400
300
200
100
0
30
45
65
80
Load (% 1RM HPC)
HPC
JS
HHP


A
3500
3000
2500
2000
1500
1000
500
0
Loading Mean Force (N)
*,#
HPC
JS
HHP
Weightlifting Derivative
B
3000
2500
2000
1500
1000
500
0
Loading Mean Force (N)
a,b
a,b,c
30
45
65
80
Load (% 1RM HPC)



3500
3000
2500
2000
1500
1000
500
0
Loading Mean Force (N)
30
45
65
80
Load (% 1RM HPC)
HPC
JS
HHP


A
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
Loading Duration (s)
*,#
HPC
JS
HHP
Weightlifting Derivative
B
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
Loading Duration (s)
30
45
65
80
Load (% 1RM HPC)



1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
Loading Duration (s)
30
45
65
80
Load (% 1RM HPC)
HPC
JS
HHP