The effects of barbell load on countermovement vertical jump power and net impulse

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THE EFFECTS OF BARBELL LOAD ON COUNTERMOVEMENT VERTICAL JUMP POWER AND NET IMPULSE

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DISCLOSURE STATEMENT

The authors report no conflict of interest.

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ABSTRACT

The aim of this study was to examine the effects of barbell load on countermovement vertical jump (CMJ) power and net impulse within a theoretically valid framework, cognisant of the underpinning force, temporal, and spatial components. A total of 24 resistance-trained rugby union athletes (average ± SD: age: 23.1 ± 3.4 yrs; height: 1.83 ± 0.05 m; body mass: 91.3 ± 10.5 kg) performed maximal CMJ under 5 experimental conditions in a randomised, counterbalanced order: unloaded, and with additional loads of 25, 50, 75 and 100% of body mass (BM). Peak and average power were maximised during the unloaded condition, both decreasing significantly ($p < 0.05$) as load increased. Net impulse was maximised with 75% of BM, which was significantly greater ($p < 0.05$) than the unloaded and 100% of BM conditions. Net mean force and mean velocity were maximised during the unloaded condition and decreased significantly ($p < 0.05$) as load increased, whereas phase duration increased significantly ($p < 0.05$) as load increased. As such, the interaction between barbell load and the underpinning force, time, and displacement components should be considered by strength and conditioning coaches when prescribing barbell loads.

INTRODUCTION

Mechanical work must be performed to accelerate and/or raise the CM of the body during dynamic athletic tasks (Cavagna, 1975). Hence, the rate of mechanical work, defined as mechanical power output (referred to as power output hereafter), is commonly hypothesised to be one of the main performance determining factors in a multitude of time-constrained dynamic athletic tasks, particularly those requiring one movement sequence to produce a high velocity at take-off or impact (Cormie et al., 2011b; Kawamori & Haff, 2004). Previously, it has been suggested that athletes who produce greater power output during unloaded (no external loading applied) and externally loaded jumping perform better in dynamic athletic tasks such as jumping (Dowling & Vamos, 1993), sprinting (Cunningham et al., 2013), and weightlifting (Hori et al., 2008). Therefore, to optimise periodic testing and training prescription, research has focused on the relationship between external loading and countermovement jump power output.

An Olympic barbell loaded with weight plates placed across the posterior aspect of the shoulders is the most commonly investigated form of external loading during countermovement jumping. The effects of barbell loading on countermovement jump power output are well reported, with the majority of studies demonstrating a systematic linear decline in power output as barbell load increases (Jaric & Markovic, 2013). However, the majority of studies have used a combination of force platform vertical ground reaction force data and barbell-derived velocity data (also referred to within the literature as the combined method) to measure countermovement jump power output (Jaric & Markovic, 2013), which Mundy et al. (2016a) demonstrated artificially inflates both peak and average power output, particularly with lighter barbell loads. As such, the effect of barbell load on countermovement jump peak and average power output may not be fully understood, and perhaps even overemphasised (e.g., training with an “optimal load” (Cormie & Flanagan, 2008; Cronin & Sleivert, 2005).

Despite the perceived importance of countermovement jump power output in the strength and conditioning community, the misuse of this mechanical variable has been heavily criticised (Knudson, 2009; Winter et al., 2016; Winter & Fowler, 2009). In brief, "power" is often expressed as a "clearly defined, generic neuromuscular or athlete performance characteristic" rather than as an application of the actual mechanical definition (Winter et al., 2016). As such, this leads to considerable inaccuracy and confusion, primarily because it often fails to represent the performance being assessed (Winter et al., 2016). Conversely, as the impulse–momentum relationship is precise and mathematically irrefutable and not only describes requirements for preface but also importantly explains prerequisites for performance, strength and conditioning coaches should perhaps focus on examining net impulse and its underpinning components of net force and time (Knudson, 2009; Winter et al., 2016; Winter & Fowler, 2009).

Although previous studies have investigated the effects of load on net impulse during countermovement jumping (Vaverka et al., 2013), a comprehensive comparison of the load–power and load–impulse relationships is yet to be reported. Further, the majority of studies investigating such relationships have not interpreted them cognisant of the underpinning force, temporal, and spatial components (Crewther et al., 2005; McMaster et al., 2014). As such, the interactions between the re-requisites for performance derived using the work–energy (force and displacement) and the impulse– momentum (force and time) relationships remain unclear, meaning external loads may be inappropriately prescribed. To demonstrate this complexity, power output may be different between 2 loads due to an increase in the force applied, an increase the displacement of the CM, a decrease in time, or a combination of all 3 – all of which have very different implications for the strength and conditioning coach. Elucidating such information may provide a greater understanding of the effects of barbell load on system CM mechanics during countermovement jump, which may reduce the misuse of power output. Further, this may also help us to better understand the nature of the acute mechanical stimulus

and its contributions to adaption (Crewther et al., 2005), as well as how such relationships can contribute to periodic testing. Therefore, the primary aim of this study was to investigate the effects of barbell load on countermovement jump power output and net impulse. The secondary aim of this study was to investigate the effect barbell load has on the underpinning force, temporal, and spatial components during countermovement jumping.

METHOD

Participants

Based on an a priori power analysis (effect size $f = 0.25$; $\alpha = 0.05$; $\beta = 0.80$), 24 male athletes (average ± SD: age: 23.1 ± 3.4 years; height: 1.83 ± 0.05 m; body mass (BM): 91.3 ± 10.5 kg) volunteered to participate during their respective preseason training period. All participants had at least 2 years of structured resistance training experience and were currently participating in a structured strength and conditioning programme as part of their respective sport (Rugby Football Union). Further, all participants were deemed technically proficient in the barbell loaded countermovement jump by a certified strength and conditioning specialist during a familiarisation session. Following a verbal and written explanation of the procedures and potential risks, the participants provided their written, informed consent. This study was approved in accordance with the University's Ethical Policy Framework for research involving the use of human participants.

Testing Procedures

Participants were instructed to report to the laboratory fully hydrated, a minimum of 2 and a maximum of 4 h postprandial, having abstained from caffeine consumption. Further, participants were instructed to refrain from alcohol consumption and vigorous exercise for at least 48 h before testing. Upon arrival, participants were led through a standardised, progressive dynamic warm-up, which included 2 sets of 6 repetitions of unloaded countermovement

jumping at submaximal efforts of 50% and 75%. The athletes then performed 2 single maximal effort countermovement jumps under 5 experimental conditions in a randomised, counterbalanced order: unloaded, and with additional loads of 25%, 50%, 75%, and 100% of BM. It is important to note that external loads were prescribed relative to BM due to the strength-independent optimum loading behaviour observed in maximum countermovement jumping (readers are referred to Jaric & Markovic, 2013). Additional loads of 25%, 50%, 75%, and 100% of BM were applied by positioning an Olympic barbell across the posterior aspect of the shoulders, whereas a wooden bar of negligible mass (mass: 0.7 kg) was used during the unloaded condition. After a 1 s quiet standing period, all CMJ were performed utilising a standard technique (Hori et al., 2007), but no attempts were made to control the depth of the countermovement (Argus et al., 2011). To control for attentional focus, no verbal encouragement was provided throughout the testing, with participants simply instructed to jump as high as possible at the beginning of each trial. A 1-min rest was provided between each countermovement jump, with 4-min rest provided between each load (Nibali et al., 2013a).

Equipment

All countermovement jumps were performed on 2 parallel force platforms (Type 9851B, Kistler Instruments Ltd., Hook, UK) embedded in the laboratory floor, each sampling vertical ground reaction force at 1000 Hz. Both force platforms were mounted according to the manufacturer's specifications, with cables and connections checked for integrity before data collection.

Data Processing

Before processing, the 1-s quiet standing period was inspected to ensure that the assumptions of 0 initial velocity and position were satisfied (Cavagna, 1975). System weight was obtained by averaging the summed vertical ground reaction force over the 1-s quiet standing period

(Owen et al., 2014). System mass was obtained by dividing system weight by gravitational acceleration. Net vertical ground reaction force was calculated by subtracting system weight from the vertical ground reaction force time curve. Net vertical ground reaction force was then integrated with respect to time to obtain the net impulse applied to the system CM. The vertical acceleration of the system CM was derived from Newton's 2nd Law (net vertical ground reaction force divided by mass), and then integrated with respect to time to obtain the vertical velocity of the system CM (referred to as velocity hereafter). Velocity was integrated with respect to time to obtain the vertical displacement of the system CM (referred to as countermovement displacement hereafter). Power output was calculated as the product of vertical ground reaction force and velocity (Mundy et al., 2016a), and then integrated with respect to time to obtain the work performed on the system CM. All integrals were solved for using the trapezoidal rule (Owen et al., 2014). The push-off phase began at the transition from negative to positive velocity (first positive velocity value) and ended at take-off (10 N threshold). Peak values were identified as the greatest instantaneous value of the respective signal within the push-off phase, whereas average values were determined by averaging the respective signal over the push-off phase. Jump height was calculated using the velocity at take-off (Hatze, 1998). Within session reliability was deemed acceptable for all dependent variables, with coefficients of variation at a 95% confidence level of less than 5%. The criteria of 5% was chosen to reflect the reliability previously observed within the literature (Hansen et al., 2011c). A total of 2 trials were chosen to minimise fatigue, but in order to identify optimal performance, the trial with the greatest take-off velocity was selected from each additional load for further analysis.

Statistical Analysis

Descriptive statistics (mean and standard deviations) were calculated for all the dependent variables. The normality of the distribution for each dependent variable was confirmed using

Z-scores for skewness and kurtosis. The effect of load on each dependent variable was analysed using a 1-way repeated measures analysis of variance. Greenhouse–Geisser adjustments of the degrees of freedom were applied if the Mauchly test of sphericity was violated. Significant main effects were analysed using Bonferroni-adjusted, post hoc tests. The magnitude of the difference between each condition was also expressed as a standardised average difference (Cohen's d effect size = [average 1 – average 2]/pooled standard deviation). Cohen's d effect sizes were interpreted according to Hopkins, Marshall, Batterham, and Hanin (2009): >0.20 (small), 0.60 (moderate), 1.20 (large), 2.0 (very large), and 4.0 (extremely large). An a priori alpha level was set to $P < 0.05$. All statistical analyses were performed using the Statistical Package for the Social Sciences (SPSS Version 20, SPSS Inc., Chicago, IL, USA).

RESULTS

Power and Net Impulse

Table 1 presents the means and standard deviations of peak power output, average power output, and net impulse. The effects of barbell load, including individual variation, on peak power output, average power output, and net impulse can be seen in Figures 1–3, respectively. Further, Figure 4 presents the differences in the individual's optimal load and the group's optimal load. Peak power and average power output were maximised during the unloaded condition, which were significantly greater than the 25% (d = 0.38 and 0.55), 50% (d = 0.44 and 0.97), 75% (d = 0.49 and 1.40), and 100% (d = 1.10 and 2.00) of BM conditions. Conversely, net impulse was maximised with 75% of BM, which was significantly greater than the unloaded (d = 0.93) and 100% (d = 0.58) of BM conditions.

INSERT TABLE 1 HERE

INSERT FIGURES 1, 2, 3 AND 4 HERE

Force, Temporal, and Spatial Components

Table 2 presents the means and standard deviations of average force, net average force, average velocity, work, phase duration, countermovement displacement, and jump height. Average net force (d = 0.57, 1.03, 1.55, and 2.09), average velocity (d = 1.60, 3.17, 4.16, and 5.44), and jump height (d = 1.64, 3.00, 3.80, and 5.33) were maximised during the unloaded condition, and decreased significantly with load. Conversely, average force (d = 0.51, 1.11, 1.63, and 2.04), work (d = 0.53, 1.02, 1.37, and 1.40), and push-off phase duration (d = 0.77, 1.47, 1.89, and 1.93) increased significantly with load. Finally, countermovement displacement was maximised under the 25% of BM condition, which was significantly greater than the unloaded (d = 0.30), 75% (d = 0.40), and 100% (d = 0.38) of BM conditions.

INSERT TABLE 2 HERE

DISCUSSION

The primary aim of this study was to investigate the effect of barbell load on countermovement jump power output and net impulse. Within the present study, unloaded peak power output was significantly greater than with additional barbell loads of 25% (d = 0.38), 50% (d = 0.44), 75% (d = 0.49), and 100% (d = 1.10) of BM. Conversely, there were no significant differences between peak power output at the 25%, 50%, and 75% of BM conditions. The effects observed are generally consistent with those previously reported within the literature, regardless of the method used (Jaric & Markovic, 2013); however, for peak power output, the decreases were generally small and not of practical importance. Therefore, focus on the identification a single load that maximises countermovement jump peak power output is perhaps overstated and practitioners should prescribe external loading parameters based on individual training needs, as well as the external loads encountered within the individual's sport (Cormie & Flanagan, 2008; Cronin & Sleivert, 2005). Further, it is important to note that there was a large intra-

individual variation in the load that maximised peak power output, with 12 participants maximising power output during the unloaded condition, 3 at 25% of BM, 3 at 50% of BM, 5 at 75% of BM, and 1 at 100% of BM. However, as demonstrated within Figure 4, the majority of these differences were either smaller than the coefficient of variation or the smallest worthwhile change. As such, for a number of individuals, the optimal load for countermovement jump peak power output is unlikely to be practically meaningful.

From a mechanistic perspective, average power output is a performance determining factor, whereas considering the sampling frequency used in this study, peak power output represents a 1 ms period corresponding to less than 1% of the push-off phase duration (Lake, Mundy, & Comfort, 2014). Although a number of studies have examined the effects of barbell load on countermovement jump average power output (Cormie et al., 2011b; Lake et al., 2014; Moir et al., 2012; Nibali et al., 2013b; Swinton et al., 2012), only Swinton et al. (2012) and Lake et al. (2014) used the force platform method. The results of the present study were in line with those of Swinton et al. (2012), with average power output significantly lower at each load than at all preceding loads. When compared to the unloaded condition, moderate to large decreases were observed (d = 0.55, 0.97, 1.40, and 2.00). Conversely, Lake et al. (2014) reported that average power output was maximised with 38.8 ± 34% of a 1 repetition maximum back squat. This may have been a result of the load that maximised average power output being identified on an individual by-individual basis and then averaged, which may be misleading. However, within the present study, when the "optimal load" was identified on an individual-by-individual basis, average power output was still maximised during the unloaded condition for all 24 athletes. As such, it is likely explained by the use of different loading spectrums, the training status of the participants, or the way in which the phase was calculated (Lake, Lauder, Smith, & Shorter, 2012a). Therefore, researchers and practitioners must be aware of such methodological differences when interpreting and comparing the results of different studies.

As intra-individual variation cannot explain the moderate to large decreases observed in average power output, it may be prudent to explain this at a system level using mechanical theory. As external load increases, the mechanical work required to jump the same height increases. However, mechanical work is anatomically constrained (because countermovement displacement is limited by human anatomy), and therefore a greater magnitude of force must be applied. Therefore, as expected, within the present study, as barbell load increased, moderate to large increases in mechanical work were observed (d = 0.53–1.40). This was underpinned by small to very large increases in average force (d = 0.51–2.04) over an approximately constant countermovement displacement (d = 0.31–0. 40). However, this was not enough to compensate for the large to extremely large decreases in average velocity (d = 1.60–5.44), which was underpinned by increases in push off phase duration (d = 0.77–1.93). Therefore, the decreases observed in power output may be explained by the increased time required to perform mechanical work, as well as the inability to apply the greater magnitude of force required to perform greater mechanical work over an anatomically constrained push-off phase. Conversely, this may be more appropriately explained mechanically at the joint level, whereby the position of the external load restricted trunk inclination by increasing the moment arm (Lees et al., 2004), limiting hip joint extensor work (Vanrenterghem et al., 2008). As changing the type and position of the external load may limit the restriction of trunk inclination and, therefore, maximise both system CM (Swinton et al., 2012) and joint mechanics, further research is warranted. Such research may help improve the efficacy of prescribing loading parameters (type of load, position of load, and magnitude of load) for jump training during the physical preparation of athletes.

As concerns have previously been raised about the misuse of power output as a mechanical variable during countermovement jumping (Knudson, 2009; Winter et al., 2016; Winter & Fowler, 2009), it may be prudent to highlight the effect barbell load has on alternative

mechanical parameters. The prescription of training loads for countermovement jumping based on the barbell load that maximises net push-off impulse remains a relatively novel idea (Crewther et al., 2005; Lake et al., 2014). This may be important for sports where athletes are repeatedly loaded by an opponent or have to accelerate through prolonged contact. However, it is important to emphasise that the work–energy and impulse–momentum theorems are essentially just spatial and temporal descriptions of the same change. Therefore, practitioners should choose which theorem to prescribe external loads based on the spatial and temporal restrictions of the respective sport and athlete.

In the present study, net impulse was maximised at 75% of BM, although this was only significantly greater than the unloaded (d = 0.93) and 100% (d = 0.58) of BM conditions. This small, linear increase in net impulse between the unloaded and the 75% of BM condition is in line with previous research. When externally loaded with a weighted vest equivalent to 10%, 20%, and 30% of BM, Vaverka et al. (2013) reported a significant linear increase in push-off net impulse. Similar findings have also been reported for “eccentric impulse”, “concentric impulse”, and “total impulse” (combined eccentric and concentric impulse) (Harris et al., 2008a; Jidovtseff, Quievre, Harris, & Cronin, 2014). The small, linear increase in net impulse between the unloaded and the 75% of BM condition can be explained using the impulse–momentum theorem. In brief, net impulse, the product of net force and time, is equal to the change in momentum, the product of mass, and change in velocity (because mass is constant during each countermovement jump). Within the present study, as barbell load increased, the system mass increased. Conversely, the average velocity of the system CM, which represents change in velocity of the system CM as its velocity is zero at the beginning of the push-off phase, decreased significantly (d = 1.60–5.44). However, the decrease in average velocity (13%, 25%, 34%, and 44% decrease) was not proportional to the increase in system mass (25%, 50%, 75%, and 100% increase). Therefore, the momentum of the system CM increased.

However, as momentum is simply the quantity of motion of the system CM, the underpinning net force and time components of net impulse must be discussed if it is to be applied appropriately within the physical preparation of athletes from different sports.

The average force applied to the system CM increased significantly as barbell load increased (d = 0.51–2.04), whereas average net force applied to the system CM decreased significantly (d = 0.57–2.09). Therefore, it appears that as barbell load increased, a greater proportion of the average force applied was to overcome the increased inertia of the system (represented by the increased mass), as opposed to accelerating it. However, the linear decline in the average net force was offset by the significant linear increase in the duration of its application, that is, push-off phase duration (d = 0.77–1.93). Therefore, net impulse initially increased linearly (e.g., unloaded to 75% of BM); however, thereafter, the increase in push-off phase duration was no longer enough to compensate for the decreasing magnitude of the net force, causing a decrease in net impulse.

Based on the findings of the present study, jump training with barbell loads of 50–75% of BM during specific phases of a periodised strength and conditioning programme may help improve the ability to accelerate through contact or when externally loaded by an opponent during sport specific events (e.g., tackling, rucking, mauling). However, as previously alluded to, net impulse may be maximised by either increasing the magnitude of the net force applied or the duration for which the application occurs. Therefore, it is important to note that due to the time constraints of most sporting activities, optimising the rate of force development may also be an important consideration for load prescription (Knudson, 2009; Lake et al., 2014; McLellan et al., 2011b). However, to the author's knowledge, there is no ubiquitously accepted method of calculating rate of force development (Hansen et al., 2011d), with the reliability of commonly used methods not acceptable within practice (Hansen et al., 2011a; Mizuguchi et al., 2015). As such, if the rate of force development is to be used in conjunction with net impulse to prescribe

jump training loads, the way in which it is calculated must first be improved, and then standardised (Knudson, 2009; McLellan et al., 2011b; Sheppard et al., 2008a).

CONCLUSION

The results of this study are important to practitioners who prescribe or may prescribe loaded countermovement jumping. It was demonstrated that additional barbell loads relative to BM significantly influence system CM mechanics during countermovement jumping. When optimising external load prescription for a periodised strength and conditioning programme, barbell loads are often prescribed based on the load that maximises either peak power or average power output. Within the present study, both peak power and average power output were maximised during the unloaded condition; however, load did not typically have a large effect. As such, further work investigating the type and position of positive external loading on both system CM and lower extremity joint mechanics may help improve the efficacy of prescribing loading parameters (type of load, position of load, and magnitude of load) for countermovement jump training during the physical preparation of athletes. As concerns have previously been raised about the misuse of power output, the relatively novel identification of loading parameters based on push-off net impulse was investigated (Lake et al., 2014), as this may help develop the ability to accelerate through prolonged contact or when loaded by an opponent during sport specific events (e.g., tackling, rucking, mauling). It was found that load only had a small effect on net impulse, which was maximised at 75% of BM. As such, a greater consideration of how the underpinning time and force components interact is required when prescribing loads.

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TABLE LEGENDS

Table 1: The effects of barbell load on power and net impulse.

Table 2: The effects of barbell load on the underpinning force, temporal, and spatial components.

TABLE 1

Table 1. The effects of barbell load on power and net impulse.

	Load				
	Unloaded	+25% of BM	+50% of BM	+75% of BM	+100% of BM
Peak Power (W)	4498 ± 418[†‡§¶]	4340 ± 403[¶]	4324 ± 381[¶]	4286 ± 448[¶]	4019 ± 455
Average Power (W)	2401 ± 256[†‡§¶]	2260 ± 253[‡§¶]	2156 ± 251[§¶]	2043 ± 256[¶]	1845 ± 301
Net Impulse (Ns)	230 ± 26	244 ± 24[*]	253 ± 24[*†]	255 ± 28[*¶]	238 ± 31

* Significantly greater than 0%: † Significantly greater than 25%: ‡ Significantly greater than 50%: § Significantly greater than 75%: ¶ Significantly greater than 100%

TABLE 2

Table 2. The effects of barbell load on the underpinning force, temporal, and spatial components.

	Load				
	Unloaded	+25% of BM	+50% of BM	+75% of BM	+100% of BM
Average Force (N)	1704 ± 231	1826 ± 250*	1981 ± 266*†	2115 ± 274*†‡	2251 ± 305*†‡§
Net Average Force (N)	804 ± 162†‡§¶	714 ± 154‡§¶	647 ± 144§¶	568 ± 143¶	472 ± 155
Average Velocity (m/s)	1.55 ± 0.13†‡§¶	1.35 ± 0.12‡§¶	1.17 ± 0.11§¶	1.03 ± 0.12¶	0.87 ± 0.12
Work (J)	709 ± 146	793 ± 171*	870 ±171*†	956 ± 215*†‡	1003 ± 273*†‡§
Phase Duration (s)	0.30 ± 0.06	0.35 ± 0.07*	0.41 ± 0.09*†	0.47 ± 0.12*†‡	0.57 ± 0.22*†‡§
Countermovement Displacement (m)	-0.35 ± 0.10	-0.38 ± 0.10*§¶	-0.37 ± 0.11	-0.34 ± 0.10	-0.34 ± 0.11
Jump Height (m)	0.34 ± 0.06†‡§¶	0.25 ± 0.05‡§¶	0.19 ± 0.04§¶	0.15 ± 0.04¶	0.10 ± 0.03

* Significantly greater than 0%: † Significantly greater than 25%: ‡ Significantly greater than 50%: § Significantly greater than 75%: ¶ Significantly greater than 100%

FIGURE LEGENDS

Figure 1. The effects of barbell load on peak power, including individual variation. * Denotes a significant ($p < 0.05$) difference. Each symbol represents a different individual

Figure 2. The effects of barbell load on average power, including individual variation. * Denotes a significant ($p < 0.05$) difference. Each symbol represents a different individual

Figure 3. The effects of barbell load on net impulse, including individual variation. * Denotes a significant ($p < 0.05$) difference. Each symbol represents a different individual

Figure 4. The intraindividual differences between the group optimal load and each individual's optimal load. A positive difference shows that the individual's optimal load was greater than the group's optimal load, whereas a negative differences shows that the individual's optimal load was lesser than the group's optimal load. The wider limits represent the coefficient of variation, whereas the narrower limits represent the smallest worthwhile change. Values within these limits are not deemed practically meaningful.

FIGURE 1

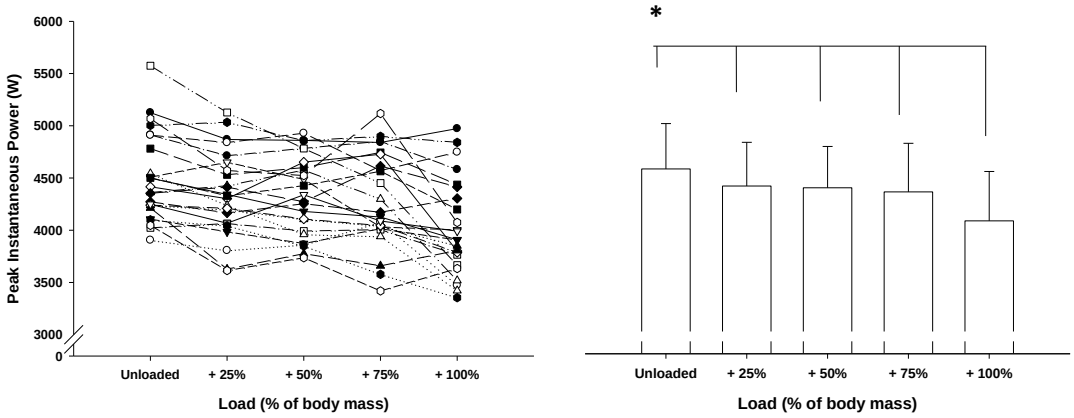

Peak Instantaneous Power (W)
6000
5500
5000
4500
4000
3500
3000
0
Unloaded
+ 25%
+ 50%
+ 75%
+ 100%
Load (% of body mass)
*
Unloaded
+ 25%
+ 50%
+ 75%
+ 100%
Load (% of body mass)

FIGURE 2

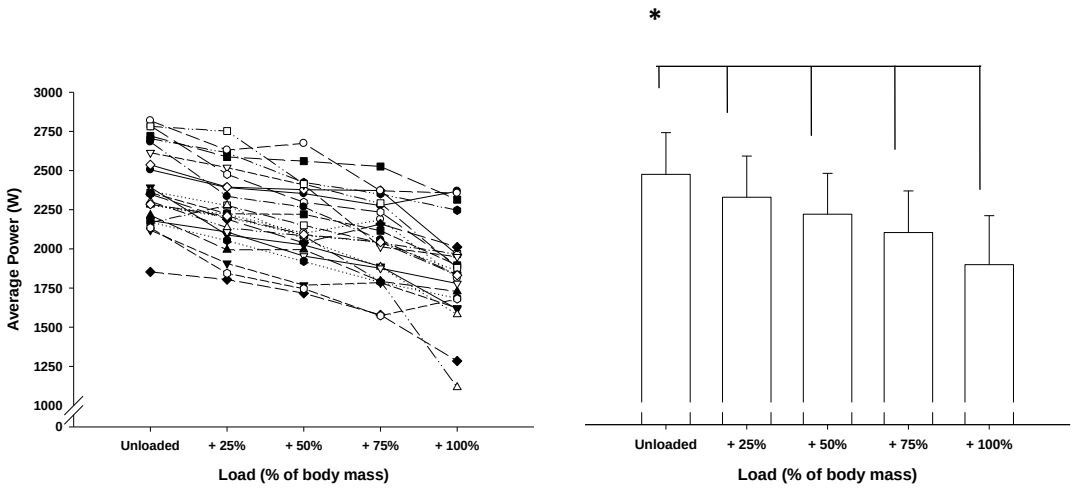

Average Power (W)
3000
2750
2500
2250
2000
1750
1500
1250
1000
0
Unloaded
+ 25%
+ 50%
+ 75%
+ 100%
Load (% of body mass)
*
Unloaded
+ 25%
+ 50%
+ 75%
+ 100%
Load (% of body mass)

FIGURE 3

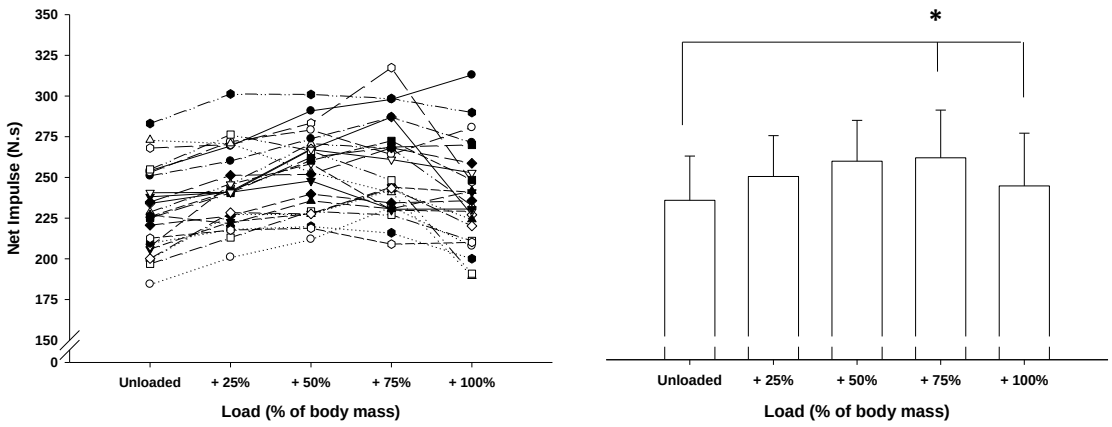
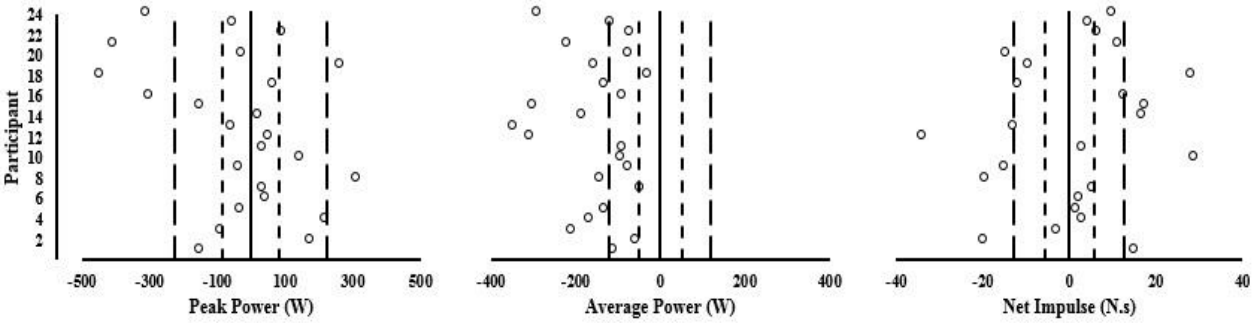

350
325
300
275
250
225
200
175
150
0
Net Impulse (N.s)
Unloaded
+ 25%
+ 50%
+ 75%
+ 100%
Load (% of body mass)
*
Unloaded
+ 25%
+ 50%
+ 75%
+ 100%
Load (% of body mass)

FIGURE 4


Participant
24
22
20
18
16
14
12
10
8
6
4
2
-500
-300
-100
100
300
500
Peak Power (W)
-400
-200
0
200
400
Average Power (W)
-40
-20
0
20
40
Net Impulse (N.s)