The effect of barbell load on vertical jump landing force-time characteristics

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Abstract

The aim of this study was to quantify the effect that barbell load has on the jump height and force-time characteristics of the countermovement jump (CMJ). Fifteen strength-trained men (mean ± SD: age 23 ± 2 years, mass 84.9 ± 8.1 kg, height 1.80 ± 0.05 m) performed three CMJ with no additional load, and with barbell loads of 25%, 50%, 75%, and 100% of body mass on two force plates recording at 1000 Hz. Propulsion and landing force-time characteristics were obtained from force-time data and compared using analysis of variance and effect sizes. Jump height decreased significantly as load increased (26 to 71%, d = 1.80 to 6.87). During propulsion, impulse increased with load up to 75% of body mass (6 to 9%, d = 0.71 to 1.08), mean net force decreased (10 to 43%, d = 0.50 to 2.45) and time increased (13 to 50%, d = 0.70 to 2.57). During landing, impulse increased as load increased up to 75% of body mass (5 to 12%, d = 0.54 to 1.01), mean net force decreased (13 to 38%, d = 0.41 to 1.24), and time increased (20 to 47%, d = 0.65 to 1.47). Adding barbell load to CMJ significantly decreases CMJ height. Furthermore, CMJ with additional barbell load increases landing phase impulse. However, while mean net force decreases as barbell load increases, landing time increases so that jumpers are exposed to mechanical load for longer. Practitioners should exercise caution when implementing loaded CMJ to assess their athletes.

Keywords: Countermovement jump, load-velocity testing, load-power testing, mechanical loading

INTRODUCTION

Loaded vertical jumping is often used to assess neuromuscular function and to identify the effect of resistance training (1, 3, 10, 11, 14, 19, 21, 22). However, loaded vertical jumping may not be without mechanical consequence. The authors have observed that landing forces tend to be larger than propulsion forces and tend to be applied over a much shorter time period, with graphical evidence previously presented in the literature (11).

Popular load-power and load-velocity testing protocols typically require athletes to jump with progressively heavier loads (1, 3, 14, 17, 19, 21, 22). This could significantly increase landing forces. Nevertheless, very little is known about the force-time characteristics of landing from vertical jumping with additional barbell loads. This could have implications for performance enhancement injury risk and prevention (12).

Despite the amount of data that have been published on vertical jumping with additional loads (1, 3, 5, 6, 14-16, 19, 21, 22), there is a paucity of research that examines the effect that load has on jump height and landing force-time characteristics (12, 13, 23). This is important because it is reasonable to assume that the height a jumper has to land from will influence landing forces, and decreases in jump height may offset increases in additional load due to reduced time for gravitational acceleration (23). If this is the case, it may be that assumptions made in the literature about the increased injury risk that loaded jumps pose will not be supported by study of landing force-time characteristics during progressively loaded vertical jumping (5, 12).

Adding weighted vest loads equivalent to around 10 ± 1% of body mass has been shown to lead to a 10% reduction in jump height (13). This increased system mass resulted in an increase in peak landing force. However, because it also resulted in decreases in jump height, landing peak force increases were limited to less than 3% (13). This suggests that potential increases in landing forces may be offset by load-based reductions in jump height. However, the interaction between the potential for the increased load to increase force upon landing along with the influence that it could have on the amount of force applied to the center of mass and the time it is applied, have not been thoroughly examined. Suchomel *et al.* (23) found that jump shrug height decreased by an average of 28% as loads equivalent to 15-20% of participants' hang power clean one repetition maximum (1RM) were added. If decrements in jump height exceed changes in landing force-time characteristics assumptions made in the literature about the increased injury potential risk that loaded jumping increasing injury risk could be refuted.

Jump height is reliant on the impulse applied to the jumper and barbell system center of mass during the propulsion phase, where impulse is the product of mean net force (force minus jumper and barbell system weight) and the time this force is applied for (17, 24). Because the acceleration of gravity is constant, landing impulse should reflect propulsion impulse. However, the duration of force application may change from the propulsion to landing phase to help minimize the magnitude of force application, due to a more compliant landing strategy. Developing a better understanding of the way impulse is applied to control the landing phase of loaded vertical jumping would enable strength and conditioning practitioners to make more informed decisions about the relative merits of using jumping-based load-power and load-velocity testing to assess neuromuscular function and identify training loads. Therefore, the aim of this study was to quantify the effect that barbell load has on the jump height and force-time characteristics of vertical jumping. It was hypothesized that jump height would decrease in response to increased barbell load, neutralizing significant increases in landing force-time characteristics, and that landing duration would demonstrate greater increases compared to any increases in propulsion duration.

METHODS

Experimental Approach to the Problem

A within-subjects design was used to quantify the effect that barbell load had on the jump height and force-time characteristics of vertical jumping. Fifteen men attended one laboratory testing session and after a warm up performed three countermovement vertical jumps (CMJ) with no additional load and with additional loads of 25, 50, 75, and 100% of their body mass. Two force plates were used to record the vertical component of ground reaction force from each jump and all dependent variables were derived from these data. Specifically, jump height, impulse, mean net force and phase duration were used to assess the effect that load had on propulsion phase performance characteristics while impulse, mean net force, phase duration and landing displacement were used to assess the effect that load had on landing phase performance characteristics.

Subjects

Fifteen strength-trained men (mean ± SD: age 23 ± 2 years, mass 84.9 ± 8.1 kg, height 1.80 ± 0.05 m) volunteered to participate after experimental aims and potential risks were explained to them and they had provided written consent to participate. This study was approved in accordance with the institution’s Ethical Policy Framework for research involving the use of human participants. Participant inclusion criteria required the demonstration of appropriate loaded CMJ technique to a certified strength and conditioning specialist. None of the subjects were involved in competitive sport at the time of testing. However, all had at least one year of resistance training experience and were participating in a structured strength and conditioning program as part of their ongoing personal training.

Procedures

Participants were instructed to report to the laboratory fully hydrated, a minimum of two and a maximum of four hours postprandial, having abstained from caffeine consumption, between 9 and 10 am. Further, participants were instructed to refrain from alcohol consumption and vigorous exercise for at least 48 hours before testing.

Standardized warm-up

All subjects performed a standardized dynamic warm-up before all testing.

This began with 2-3 minutes of upper- and lower-body dynamic stretching using a previously described warm up (15). Specifically, subjects performed 2 circuits of 10 repetitions each of ‘arm swings’, ‘lunge walk’, ‘walking knee lift’, and ‘heel to toe lift’ (2), and unloaded, sub-maximal CMJ.

Testing

Subjects performed three CMJ with no additional load (body mass: BM) and with additional barbell loads of 25, 50, 75 and 100% of BM in ascending order. For the BM condition, participants positioned a wooden bar of negligible mass (mass: 0.7 kg) across the posterior aspect of the shoulders, thus replicating the kinematics of the loaded conditions where subjects took an appropriately loaded Olympic barbell (20 kg) from portable squat stands (Pullum Sports, Luton, UK). All CMJ were performed utilizing a standard technique (2, 10), with no attempts made to control countermovement amplitude. One minute of rest was provided between each trial, with four minutes of rest provided between each load.

Equipment

All CMJ were performed on two parallel Kistler force platforms (Type 9851B; Kistler Instruments Ltd., Hook, UK) embedded in the floor of the laboratory, each sampling at 1000 Hz. Vertical ground reaction force (VGRF) data from both force platforms were synchronously acquired in VICON Nexus (Version 1.7.1; Vicon Motion Systems Ltd., Oxford, UK).

*****Insert Figure 1 and 2 about here, please*****

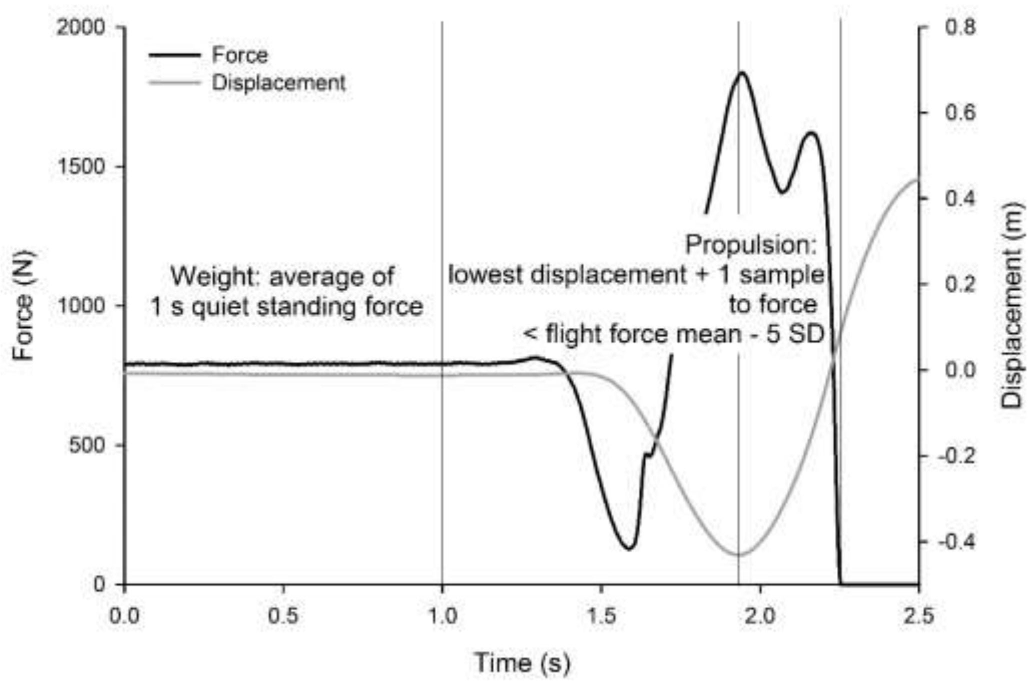

Figure 1. Calculation of weight and identification of the propulsion phase.

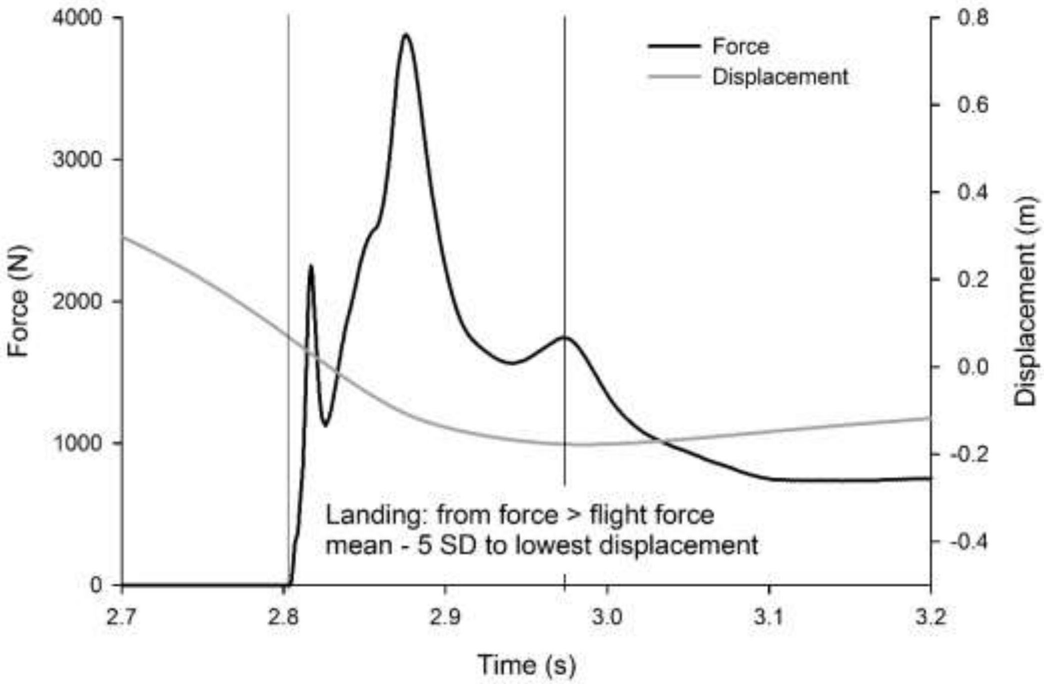

Figure 2. Identification of the landing phase.

Data Analysis

Raw force data were analyzed using custom LabVIEW software (Version 10.0; National Instruments, Austin, TX, USA). Data were calculated from the three trials with each load and then averaged for further analysis, all three trials were used in the reliability analysis. The dependent variables were: jump height, propulsion impulse, mean net force, and time, and landing impulse, mean net force, and time.

Jump height was calculated from take-off velocity (take-off velocity^2 ÷ 2g) (20). Velocity was obtained by integrating acceleration with respect to time using the trapezoid rule using the method described by Owen *et al.* (18) Acceleration was obtained by dividing force (less weight [system weight for loaded trials]) by body mass (system mass for loaded trials). Briefly, body weight was obtained by averaging one second of force-time data as the participants stood still while awaiting the word of command to jump. This was recorded during each trial and the subject was instructed to stand perfectly still. The standard deviation (SD) of this 'quiet standing' phase was also calculated and the start threshold of body weight less 5 standard deviations was calculated. The final part of this process was to then go back through the force-time data by 30 ms as it has been shown that this positions the start at a point when the subject is still motionless. Therefore, the assumption of zero velocity was not compromised negatively, which could impact the calculation of subsequent kinetic and kinematic data (18). Figure 1 shows how the propulsion phase was identified.

Take-off and landing were identified in three stages (Figure 1 and 2). First, the first post-countermovement force value less than 10 N and the next force value greater than 10 N were identified; second, points 30 ms after and before these points, respectively were identified to identify the center 'flight phase' array; third, mean and SD 'flight phase' force was calculated, and mean 'flight phase' force plus 5 SD was used to identify take-off. The landing phase ended the when center of mass reached its lowest post impact position (see Figure 2). Displacement was obtained by integrating velocity with respect to time using the trapezoid rule. Propulsion and landing impulse were obtained by summing impulse over the respective propulsion and landing phases. Impulse was obtained by integrating net force (force less weight) with respect to time using the trapezoid rule. Jumping and landing mean force was obtained by averaging vertical force over the respective jumping and landing phases. Phase durations were also recorded.

Statistical Analyses

All data were presented as means ± SD. To address the hypothesis that jump height would decrease in response to barbell load increase, jump height, propulsion and landing impulse, mean net force, and time, and landing displacement were compared across the 5 loads using 1-way repeated measures analysis of variance. Where appropriate, paired sample *t* tests were performed to establish the effect of additional load and the Bonferonni correction applied. Intraclass correlation coefficients were calculated to assess the reliability of the dependent variables. Finally, a 2-way repeated measures analysis of variance was used to establish whether there were any significant differences between propulsion and landing phase impulse across the different loads. All statistical analyses were performed using SPSS (Version 23.0, SPSS Inc., Armonk, NY, USA), and an alpha level of $p \leq 0.05$ was used to indicate statistical significance. Cohen's *d* effect sizes were quantified using the scale recently presented by Hopkins *et al.* (9), where *d* of 0.20, 0.60, 1.20, 2.0, and 4.0 represented small, moderate, large, very large and extremely large, effects respectively. Finally, relative reliability was assessed using intraclass correlation coefficients (two-ways random effects model, [ICC]), while absolute reliability was assessed using percentage coefficient of variation (CV) (4). The magnitude of the ICC was determined using the criteria set out by Cortina (7), where $r \geq 0.80$ is considered highly reliable. The magnitude of the CV was determined using the criteria set out by Banyard *et al.* (4), where >10% is considered poor, 5-10% is considered moderate, and <5% is considered good.

*****Insert table 1 and table 2 about here please*****

Table 1. Dependent variable reliability intraclass correlation coefficients (95% confidence intervals).

	0%	25%	50%	75%	100%
Propulsion impulse	0.96 (0.91-0.99)	0.97 (0.92-0.99)	0.96 (0.91-0.99)	0.97 (0.92-0.99)	0.97 (0.92-0.99)
Propulsion mean force	0.93 (0.84-0.98)	0.97 (0.92-0.99)	0.98 (0.94-0.99)	0.97 (0.92-0.99)	0.98 (0.94-0.99)
Propulsion time	0.96 (0.91-0.99)	0.95 (0.88-0.98)	0.98 (0.95-0.99)	0.95 (0.89-0.98)	0.95 (0.88-0.98)
Jump height	0.90 (0.77-0.97)	0.96 (0.89-0.98)	0.95 0.87-0.98)	0.94 0.85-0.98)	0.95 (0.88-0.98)
Landing impulse	0.97 (0.92-0.99)	0.90 (0.75-0.96)	0.95 (0.88-0.98)	0.96 (0.90-0.98)	0.97 (0.93-0.99)
Landing mean force	0.92 (0.80-0.97)	0.87 (0.69-0.96)	0.96 (0.89-0.99)	0.95 (0.89-0.98)	0.98 (0.96-0.99)
Landing time	0.94 (0.85-0.98)	0.92 (0.81-0.98)	0.98 (0.95-0.99)	0.96 (0.91-0.99)	0.97 (0.94-0.99)
Landing displacement	0.96 (0.89-0.98)	0.97 (0.93-0.99)	0.98 (0.95-0.99)	0.99 (0.97-1.00)	0.98 (0.96-0.99)

Table 2. Dependent variable reliability coefficient of variation (95% confidence intervals).

	0%	25%	50%	75%	100%
Propulsion impulse	2.3 (1.4-3.2)	2.2 (1.6-2.9)	2.6 (1.8-3.4)	2.9 (2.4-3.5)	3.6 (2.6-4.7)
Propulsion mean force	5.0 (3.3-6.8)	5.6 (3.7-7.5)	5.1 (3.5-6.8)	7.6 (5.4-9.8)	9.1 (6.0-12.1)
Propulsion time	3.9 (2.6-5.2)	4.5 (2.7-6.2)	3.8 (2.6-5.1)	6.2 (4.0-8.5)	7.5 (4.2-10.8)
Jump height	4.6 (2.7-6.5)	4.5 (3.3-5.8)	5.1 (3.4-6.7)	5.9 (4.8-7.1)	7.4 (5.2-9.5)
Landing impulse	2.7 (1.9-3.6)	4.5 (2.4-6.6)	4.0 (2.7-5.3)	4.5 (3.0-6.0)	5.6 (4.4-6.8)
Landing mean force	6.7 (4.4-9.1)	8.3 (4.0-12.6)	3.9 (2.3-5.5)	4.3 (2.7-5.9)	2.7 (1.8-3.5)
Landing time	11.4 (7.8-15)	12.3 (7.4-17.2)	8.3 (5.4-11.2)	11.9 (8.7-15.0)	10.1 (7.7-12.5)
Landing displacement	10.8 (6.4-15.2)	15.1 (4.5-25.7)	8.4 (5.3-11.6)	8.1 (5.6-10.7)	8.5 (6.8-10.2)

RESULTS

The results of the reliability analysis are presented in Table 1 and 2. Relative reliability was high for all variables. However, while absolute reliability was good for many variables during CMJ with just body mass, the addition of load negatively affected the absolute reliability of most variables to moderate and in some cases poor. Descriptive statistics and the results of the statistical analysis are presented in Table 3.

Load significantly affected all dependent variables. Jump height decreased significantly ($p < 0.001$) as load increased (26 to 71%, $d = 1.80$ to 6.87). Propulsion impulse increased significantly ($p < 0.001$) with load from 0 to 75% (6 to 9%, $d = 0.71$ to 1.08), but there no significant differences between 0 and 100%, 25 and 100%, 50 and 75%, 50 and 100%, and 75 and 100%. Propulsion mean net force decreased as load increased (10 to 43%, $d = 0.50$ to 2.45), while propulsion duration increased with load (13 to 50%, $d = 0.70$ to 2.57). Landing impulse increased with load from 0 to 75% (5 to 12%, $d = 0.54$ to 1.01), but there were no significant differences between 0 and 100%, 25 and 50%, 25 and 100%, 50 and 75%, 50 and 100% and 75 and 100%. Landing mean net force decreased with load (13 to 38%, $d = 0.41$ to 1.24), while landing time increased as load increased (20 to 47%, $d = 0.65$ to 1.47). Furthermore, there were significant differences between the propulsion and landing phase impulse (4%, $p = 0.039$, $d = 0.34$) but no load by phase interaction ($p > 0.05$). Finally, additional load did not significantly affect vertical displacement of the center of mass during landing ($p = 0.346$).

*****Insert Table 3 about here please*****

Table 3. Mean (SD) descriptive vertical jump and landing performance data and the results of the statistical analysis.

Load (%BM)		Pr Jz (Ns)	Pr MNF (N)	Pr time (s)	Jump height (m)	Land Jz (Ns)	Land MNF (N)	Land time (s)	Land Sz (m)
0%	Mean	226	717	0.32	0.34	233.22	1035	0.25	0.33
	SD	(19)	(105)	0.04	(0.05)	(23.16)	(336)	(0.09)	(0.11)
25%	Mean	239	636	0.39	0.25	246.32	900	0.31	0.38
	SD	(19)	(126)	0.06	(0.05)	(25.58)	(328)	(0.11)	(0.14)
50%	Mean	249	572	0.45	0.20	256.93	830	0.35	0.38
	SD	(24)	(132)	0.09	(0.04)	(30.74)	(287)	(0.12)	(0.14)
75%	Mean	249	502	0.52	0.15	263.87	794	0.39	0.37
	SD	(25)	(136)	0.12	(0.05)	(37.55)	(327)	(0.16)	(0.15)
100%	Mean	239	408	0.64	0.10	253.50	642	0.48	0.38
	SD	(29)	(148)	(0.21)	(0.02)	(51.93)	(298)	(0.22)	(0.16)
	F =	17.63	127.00	39.89	904.16	6.97	22.09	22.89	1.14
	p =	<0.001	<0.001	<0.001	<0.001	0.005	<0.001	<0.001	0.346
0 vs. 25%	*p* =	<0.001	<0.001	<0.001	<0.001	<0.005	<0.005	<0.001	ns
	d =	-0.71	0.71	-1.30	1.80	-0.54	0.41	-0.65	0.37
0 vs. 50%	*p* =	<0.001	<0.001	<0.001	<0.001	<0.001	<0.005	<0.005	ns
	d =	-1.08	1.23	-2.05	3.01	-0.88	0.66	-0.94	0.34
0 vs. 75%	*p* =	<0.001	<0.001	<0.001	<0.001	<0.005	<0.005	<0.01	ns
	d =	-1.04	1.79	-2.53	3.80	-1.01	0.73	-1.15	0.30
0 vs. 100%	*p* =	ns	<0.001	<0.001	<0.001	ns	<0.001	<0.005	ns
	d =	-0.55	2.45	-2.57	6.86	-0.54	1.24	-1.47	0.33
25 vs. 50%	*p* =	<0.001	<0.001	<0.001	<0.001	ns	ns	ns	ns
	d =	-0.45	0.50	-0.90	1.08	-0.38	0.23	-0.29	-0.03
25 vs. 75%	*p* =	<0.01	<0.001	<0.001	<0.001	<0.05	ns	ns	ns
	d =	-0.43	1.02	-1.55	2.00	-0.56	0.32	-0.58	-0.06
25 vs. 100%	*p* =	ns	<0.001	<0.001	<0.001	ns	<0.001	0.009	ns
	d =	0.00	1.66	-1.93	4.29	-0.19	0.82	-0.99	0.00
50 vs. 75%	*p* =	ns	<0.001	<0.001	<0.001	ns	ns	0.54	ns
	d =	0.01	0.52	-0.70	1.08	-0.20	0.12	-0.33	-0.03
50 vs. 100%	*p* =	ns	<0.001	<0.001	<0.001	ns	<0.001	0.044	ns
	d =	0.37	1.17	-1.31	3.17	0.08	0.64	-0.78	0.03
75 vs. 100%	*p* =	ns	<0.001	<0.001	<0.001	ns	<0.001	ns	ns
	d =	0.35	0.66	-0.76	1.43	0.23	0.49	-0.45	0.05

*%BM = percentage of body mass; Pr = propulsion phase; Jz = vertical impulse; MNF = mean net force; Land = landing phase; Sz = vertical displacement

DISCUSSION

This is the first study to examine the effect that progressive barbell loading has on jump height and the propulsion and landing force-time characteristics of CMJ. The results showed that in general as load increased, jump height decreased. Furthermore, while propulsion impulse increased, this was underpinned by decreases in propulsion mean net force that were outweighed by increases in propulsion duration. Finally, and most importantly for this study, this same pattern was found during the landing phase: landing impulse tended to increase because decreases in landing mean net force were outweighed by increases in landing time.

In agreement with previous research, adding load to jumping caused significant decreases in jump height (13, 23). However, as with discrepancies in the existing literature, the magnitude of jump height decrements varied. For example, research has shown that adding a weight vest equivalent to ~10% of body mass causes commensurate decrements in jump height (13). However, other research has shown that adding an average load increase of ~28% of hang power clean 1RM to jump shrug performance causes a 21% decrement in jump height (23). Interestingly though, and in spite of its use in popular load-power and load-velocity testing protocols, investigators have not studied how adding load to jumping tasks influences the mechanisms underpinning jump height. Dividing propulsion impulse by jumper (or system) mass yields the instantaneous velocity at the end of the phase of interest, in this case take-off velocity, which ultimately dictates jump height.

The results of this study showed that adding load to CMJ demanded significantly greater propulsion impulses. However, propulsion impulse increments were not commensurate with the increases in system mass (7 ± 2% vs 25% of body mass), which explains the decrements in jump height. Furthermore, the constituent parts of propulsion impulse (mean net force and time) were also affected by load. This is interesting because it provides insight into the neuromuscular response adopted by our subjects to adding load to CMJ. On average propulsion mean net force decreased by 26 ± 14% while propulsion time increased by 34 ± 14%. From a training perspective this is interesting because it shows that adding load significantly increases the time required to apply the necessary mean net force during propulsion. Monitoring an athlete’s ability to jump higher in less time with the same load would mean that the athlete had increased their capacity to apply force during a ballistic movement. This could have important practical implications for the strength and conditioning process (6).

Because the acceleration of gravity is constant, both propulsion and landing impulses should reflect one another. Thus, it should take the same impulse to propel one into the air as it should to arrest their negative velocity upon landing. However, the results of this study showed that there was a small but significant difference between the propulsion (240.49 ± 24.46 Ns) and landing (250.77 ± 35.94 Ns) impulses. It is likely that this is a consequence of the differences between take-off and landing position that have been posited to cause differences between jump heights obtained from flight time and take-off velocity (8, 20). This reinforces the need for practitioners to exercise caution when choosing a method to obtain loaded vertical jump height because these differences could have a direct impact on the accuracy of vertical jump heights obtained from flight time. However, this remains an area that requires further study and is beyond the scope of this study.

Although jump height decreased in response to load increases, landing impulse increased (9.5 ± 2.9%). The mean net force component of landing impulse decreased, while landing duration increased. This reflected the changes found during the propulsion phase. With regards to the decrements in mean net force, these changes occurred because subjects were not able to maintain the acceleration of the system mass during propulsion as load increased. Therefore, arresting the negative acceleration of the system during landing required less mean net force in accordance with Newton's second law of motion. Thus, it might be reasonable to assume that these results show that from a mechanical consequence perspective, incrementally loaded vertical jumping does not pose an increased risk of injury. However, it should be remembered that if impulse values increase or are maintained, but the force component does not change, or indeed decreases, then the time component must increase. This means that although subjects were exposed to less load, in the form of mean net force, they were exposed to them for significantly longer. This could have significant implications from an injury risk perspective and warrants further research. At the very least, it suggests that practitioners who employ load-power and load-velocity protocols to assess the neuromuscular capacity of their athletes, or use these protocols to identify training loads, should pay careful attention to athlete landing strategies.

While this study provides some important new data that improves our understanding of the effect of incremental loading on the mechanical demands of vertical jumping, it is not without its limitations. The main limitation of this study is the fact that we did not consider vertical jumping kinematics. This is relevant because it is possible that increases in load elicited changes in the movement strategy during both propulsion and landing. For example, the results of this study clearly show that the force application duration component of both the propulsion and landing impulse increased in response to incremental loading. However, we were unable to explain how these increases manifested themselves from a movement strategy perspective. Therefore, while the results of this study provide a greater understanding of the effect that incremental loading has on the force application duration of the propulsion and landing phase, this area could benefit from research into the effect it has on lower-body kinematics. For example, it is reasonable to assume that because jump height decreases in response to incremental loading the increased force application duration during the landing phase could be underpinned by greater flexion of the hip and knee, or perhaps both, and could be implemented to absorb jumper perceptions of the greater force they were about to be exposed to during landing. This could have important implications for the field measure of key CMJ performance variables, like jump height. This is because many field based methods are based on flight time and changes in landing strategy could affect the accuracy of this (8, 20). Additionally, while our loading strategy mirrors the loading strategy used by some researchers who have studied the load-power or load-velocity relationships (16, 21), others have used loads relative to their subjects' back squat 1RM (1, 6, 14, 22), or absolute loads (3). Therefore, the results of this study should be interpreted with caution with regards to other research in the load-power and load-velocity relationships that have used different loading strategies (1, 6, 14, 22).

In conclusion, adding barbell load to CMJ significantly and negatively affects CMJ height. Furthermore, CMJ with additional barbell load significantly increases landing phase impulse. However, while the mean net force applied by the athlete decreases as barbell load increases, their landing duration increases so that they are exposed to mechanical load for longer. Further analysis is required to establish whether lower-body kinematics change during landing with additional load.

PRACTICAL APPLICATIONS

Although the forces applied by athletes decrease as additional barbell loads increase, the time athletes are exposed to these forces increases significantly, leading to significantly larger impulses. While jumping with additional load is a popular way of assessing the load-power and load-velocity relationships, as load increases so too does the mechanical load the athlete is exposed to. Therefore, it is important that these additional loads, specifically the higher ones, are chosen very carefully by strength and conditioning practitioners as they may not always be warranted. Furthermore, increases in landing phase duration may be a consequence of landing movement strategy adaptations – this could influence training adaptations and influence the methods that are often used to assess jump height, specifically the flight time method. It is therefore recommended that practitioners exercise caution when implementing loaded vertical jumping to assess the neuromuscular function of their athletes and to identify the effect of strength and conditioning programs. It is suggested that impulse is explored during these tasks where possible, to determine any associated changes in both the magnitude and duration of force application, to fully understand the causes of an associated changes in velocity. Finally, when implementing jumping variations, it is important to note that while lighter loads may maximize power, jumping with heavier loads may enhance an individual’s propulsive force production capacity as well as train force absorption characteristics by requiring large impulse generation during both propulsion and landing phases.

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Figures

Figure 1. Calculation of weight and identification of the propulsion phase.

Figure 2. Identification of the landing phase.

Tables

Table 1. Dependent variable reliability intraclass correlation coefficients (95% confidence intervals).

Table 2. Dependent variable reliability coefficient of variation (95% confidence intervals).

Table 3. Results of the repeated measures analysis of variance and post hoc testing on jump height, and propulsion and landing phase force-time characteristics.