Balancing Injury Risk and Power Development by Weighted Jump Squat Through Controlling Eccentric Loading

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Abstract

Songsupap, T, Newton, RU, and Lawsirirat, C. Balancing injury risk and power development by weighted jump squat through controlling eccentric loading. *J Strength Cond Res* 35(11): 2999–3005, 2021—Weighted jump squat (WJS) training is highly effective for increasing neuromuscular power but entails higher injury risk than traditional resistance training because of the impact of landing. Braking mechanisms can be used to control the landing impact; however, the optimal eccentric loading condition that balances injury risks and power output is still unclear. The purpose of this study was to assess different eccentric braking conditions. Twenty-two male varsity basketball players aged 20.8 ± 1.1 years and a 1 repetition maximum (1RM) of back squat-to-body mass ratio of 2.0 ± 0.2 participated in the study. The subjects performed 2 sets of WJS of 6 repetitions with additional 30% of 1RM load under 4 randomly assigned conditions: (a) traditional load, no braking (B0), (b) 25% braking load reduction during landing (B25), (c) 50% braking load reduction during landing (B50), and (d) 100% braking load reduction during landing with release at touchdown (B100R). A repeated measures analysis of variance was used to determine differences of dependent variables: peak power output, peak force, peak velocity, and impulse. B100R resulted in statistically lower eccentric peak force and impulse for the first 50 milliseconds than the other 3 conditions ($p < 0.05$), but the largest concentric peak power. Furthermore, B0 resulted in statistically lower concentric peak power and peak velocity than the other 3 conditions ($p < 0.05$). We suggest that B100R was a more favorable loading condition that balanced injury risk and power production in WJS.

Key Words: stretch-shortening cycle, force, impulse, ballistic landing impact

Introduction

Ballistic resistance training (BRT) has been extensively reported to enhance neuromuscular power and athletic performance when compared to traditional resistance or plyometric training (4,6,23,40). Ballistic resistance training requires athletes to produce projection of an object into free flight, which can be a barbell, dumbbells, weighted vest etc. (3,14). To produce a flight phase, athletes need to generate sufficient impulse to accumulate enough vertical momentum to project the body or object into space resulting in higher power output when compared to non-BRT (17). Weighted jump squat (WJS) is one type of BRT primarily emphasizing maximal power output of the lower body through triple extension to produce relatively high power output and, thus, acceleration (14,23,35). Athletes usually perform WJS with a barbell on the shoulders and lower themselves to a self-selected depth before attempting to jump as high as possible. After the peak in flight, there is acceleration due to gravity during which velocity increases under free fall until the feet contact the ground and the athlete must arrest the developed momentum through eccentric contraction of the hip, knee, and ankle extensors; decelerating the body; and absorbing the impact force of landing (12,14,15). In repeated jumps, this phase forms the countermovement for the subsequent jump, concentrically contracting the muscles maximally to produce peak power output (14,17). As a result, concentric peak power (PP_{CON}), concentric peak force (PF_{CON}), and concentric peak velocity (PV_{CON}) during a WJS are much higher than those during traditional back squat as the goal is to achieve maximum jump height (JH). This performance requires a high level of strength and stiffness regulation with an enhanced ability to tolerate high stretch loads to prevent injury from landing and translate the momentum developed into force leading to improved subsequent jump performance (5,21,41).

PP_{CON} has been shown to be significantly related to athletic performance, such as in sprinting or jumping (1,7,26,31). Consequently, strength and conditioning specialists focus on improving PP_{CON} by determining appropriate additional loading to optimize the force-velocity-power relationship (3,9,16,20,33,35). Performing jumps with a load greater than body mass has been demonstrated to facilitate adaptations for increased power output and improved sports performance (40), but the additional load has been associated with an increased risk of injuries and fatigue and elicits reflex inhibition during the landing phase (8,19,27,32,38). Impulse over the first 50 milliseconds ($IMP50ms_{ECC}$) and eccentric peak force (PF_{ECC}) are often used as indicators of injury risk reported in the literature. A 50 millisecond epoch is selected because the neuromuscular system has a limited reaction time response between 50 and 75 milliseconds (8,14,15,27). Hence, various braking mechanisms are introduced and activated to unload or reduce the high stretch load during landing to decrease training fatigue, impact force, impulse, and thus, injury risk (12,14,15,20,21,23–25,35). Humphries et al. (15) reported that applying braking during landing reduced

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PF_{ECC} and $IMP50ms_{ECC}$ by 155 and 200%, respectively. However, limiting the eccentric loading may inhibit training induced neuromuscular adaptations for increased ballistic performance. For example, research by Hoffman et al. (12), Hori et al. (14), and Newton et al. (23) showed that strength and power improvement was inhibited when subjects performed under unloaded or braked WJS as it is evident that some minimal level of eccentric loading is required for strength gain (22,28,30,37,39).

Although totally removing the landing load can reduce injury risk by limiting impact force and impulse, it impedes the strength and power enhancement because there is an insufficient training stimulus to induce morphological and neural adaptations (12). Nuzzo and McBride (24) showed that subjects performing unloaded WJS had significant reductions in eccentric phase muscle activity yielding a negative effect on concentric phase performance, and the authors concluded that unloaded WJS was not recommended. By contrast, Cormie et al. (5) showed that BRT without braking elicited changes in a multitude of eccentric phase contributions to improvements in jump performance. Therefore, it is evident that the eccentric loading condition is important for acutely facilitating the following concentric phase and chronic training adaptations for enhanced jump performance (5,10,28). A balance must be struck between performance enhancement and the problem of landing with large momentum, but there are limited studies investigating the effects of different eccentric loading conditions on PP_{CON} during WJS. There are several studies comparing the effects between loaded and unloaded WJS performance (12,14,15), but only between 2 conditions, 0% or 100% unloaded. As PF_{ECC} capability can be as much as 50% of force production in the concentric phase (36), manipulating the eccentric load may elicit enhancements to concentric performance by higher preloading and muscle active state providing more optimal motor unit recruitment, firing rate, and stretch-shortening cycle (SSC) potentiation while still moderating injury risk (5,22,39).

When landing from the WJS, it is evident that the initial impact spike is most problematic (15) because the peak force, although transient, can be many times body mass. Braking systems for ballistic training can be programmed to provide varying levels of resistance at different positions in the movement. Previous research (14,15) implemented braking during the landing phase where the reduction of load was continuous from maximum height to the lowest height, that is, bottom of the countermovement. Although this greatly reduced the landing impact spike (15), it also compromised the eccentric loading of the muscle. It may be advantageous to remove the braking at the point of landing and return the full load to the subject so they can use a more dynamic eccentric phase. However, no investigation has yet examined the appropriate braking position or eccentric loading condition for WJS that balances injury risk and power development.

Therefore, our aim was to compare the effects of different eccentric loading conditions: 0, 25, and 50% reduction throughout the downward phase with 100% reduction to the point of ground contact and then brake release. These reductions in load were selected to be compared based on previous research demonstrating improved jump performance (11,30). We sought to determine which condition provided optimal balance between reducing injury risk and facilitating peak power output. We hypothesized that WJS for which 100% of the additional load was removed until ground contact would provide the lowest $IMP50ms_{ECC}$ but then released to load the eccentric phase more effectively to yield the greatest PP_{CON} because the removal of additional load until ground contact helped reduce the impact due to the additional load while releasing the load at the eccentric phase would more optimally activate the SSC facilitating the subjects to create high peak power in the subsequent jump. The findings of this study will allow us to better understand the effects of eccentric loading conditions and assist coaches to optimize training for leg extensor power output.

Methods

Experimental Approach to the Problem

A counterbalance research design was used to compare concentric and eccentric kinetics and kinematics across 4 different eccentric loading conditions: (a) traditional load with no brake, (b) 25% load reduction during landing, (c) 50% braking load reduction during landing, and (d) 100% braking load reduction during landing with release at touchdown. In this study, male varsity basketball players were recruited. All subjects were randomly assigned into 4 groups and completed 4 different experimental tasks across 4 weeks rotating through the 4 conditions. In each experimental session, the subjects performed 2 sets of WJS of 6 repetitions with 30% of their 1RM with 4 minutes rest between sets. Each session was separated by 1 week. The research design enabled us to compare the effects of the different eccentric loading conditions on force, velocity, and power during WJS and determine which condition would be most appropriate for power training, yielding the lowest $IMP50ms_{ECC}$ while providing the greatest PP_{CON}.

Subjects

Twenty-four male varsity basketball players who were currently competing in university games and older than 18 years (age range: 20–24 years) volunteered to participate in this study. All subjects had previous experience in resistance training for at least 2 years before the experiment and maintained off-season training (strength/power phase) during the experimental period. Inclusion criteria were the ability to perform a 1RM back squat of at least 1.6 times body mass (4). The 1RM back squat was tested following the protocol of Hori et al. (14). Exclusion criteria included: use of any drugs or muscle stimulants, any injuries, or illness that would affect their performance. Two players were excluded from the study because of injuries during their normal training unrelated to the study. Thus, only 22 subjects completed all aspects of this study. Descriptive statistics of the subjects are presented in Table 1. Ethics approval was granted by the Human Research Ethics Review Committee of Chulalongkorn University and complied with the principles of the Declaration of Helsinki. All subjects were informed of the risks and benefits of the study, and written informed consent was received from all subjects before their participation in the study.

Table 1
Characteristics of subjects (*n* = 22).

Characteristics	$\bar{x} \pm SD$
Age (y)	20.8 ± 1.1
Body mass (kg)	69.6 ± 12.5
Body fat (%)	15.8 ± 4.0
Height (cm)	171.9 ± 7.1
1RM of back squat (kg)	142.1 ± 31.4
Relative 1RM	2.0 ± 0.2
Experience (y)	3.1 ± 0.8

Procedures

After providing explanation of the testing procedures and completing the written informed consent process, the subjects were asked to visit the laboratory 6 times. The first session was to collect biometric data and determine the 1RM back squat. Body mass, height, and percentage body fat were measured by a body composition analyzer with ultrasonic height measurement (ioi 353; Jawon Medical, Kyungsan City, Korea). Next, 1RM back squat was determined using the protocol established by Hori et al. (14). The protocol has been reported to have an intraclass correlation coefficient of 0.97 and coefficient of variation of 4.6%. The second visit was an introduction session and a familiarization session for the subjects. The familiarization session was completed 1 week before the first experimental session so as to avoid any residual fatigue.

The subjects were randomly assigned to 1 of 4 groups, with each group starting with a different condition in the first week. For each testing session, the subjects were instructed not to exercise and to refrain from food, caffeine, and alcohol consumption for at least 2, 3, and 24 hours before and to sleep adequately before the test session. Once the subjects arrived at the laboratory, they performed an identical warm-up session where they cycled on an ergometer (828E; Monark Exercise AB, Vansbro, Sweden) for 5 minutes at 100 W intensity at a speed of 60 rpm. They then rested for 4 minutes before performing 1 set of 6 repetitions of WJS with an Olympic barbell (20 kg) for specific warm-up (14,20). The subjects then performed 6 maximal consecutive WJS for 2 sets with a 4-minute rest interval. The barbell was loaded to 30% of each subject's previously determined 1RM because this has been widely reported as an appropriate load for ballistic training (14,20,40). Each session was separated by 1 week. To eliminate confounding effects, the subjects were scheduled to be tested at the same time each session. The order of testing for each group rotated and is presented in Table 2.

Eccentric Loading Conditions. There were 4 eccentric loading conditions in this study.

- Traditional load with no braking (B0): the subjects performed the WJS with 30% of 1RM. There was no braking applied, and so during the downward phase, from the peak of the jump to the bottom of the countermovement the subjects were loaded with body mass plus 30% of 1RM.
- Twenty-five percent braking load reduction (B25): the subjects performed the WJS with body mass plus 30% of 1RM as per condition 1. However, during the downward phase, the braking system was applied to reduce the 30% of 1RM by 25%. The subjects were thus loaded with body mass plus 22.5% 1RM from the peak of the jump to the bottom of the countermovement.
- Fifty percent braking load reduction (B50): the subjects performed the WJS with body mass plus 30% of 1RM as per condition 1. However, during the downward phase, the braking system was applied to reduce the 30% of 1RM by 50%. The subjects were thus loaded with body mass plus 15% 1RM from the peak of the jump to the bottom of the countermovement.
- One hundred percent braking load reduction with release (B100R): the subjects performed the WJS with body mass plus 30% of 1RM as per condition 1. However, during the downward phase, the braking system was applied to reduce the 30% of 1RM by 100% and then release at the point of ground contact. The subjects were thus loaded with body mass only from the peak of the jump to ground contact and then body mass plus 30% 1RM from this point to the bottom of the countermovement.

Data Collection and Analysis. The experimental setup is presented in Figure 1. Each subject performed WJS within a power cage (FT700; Fitness Technology, Adelaide, Australia). The power cage includes an electromagnetic braking mechanism (Ballistic Braking System; Fitness Technology) that attaches to the middle of the barbell. This electromagnetic braking system is only applied during the downward phase controlled by a computer and software program (Ballistic Measurement System, BMS; Innervations, Perth, Australia) and has been used in several studies (14,15,23,35,40).

Vertical ground reaction force (VGRF) was recorded using a force platform (400 s; Fitness Technology). To control and ensure the braking mechanism was switched off at ground contact, a linear position transducer (PT5A; Celesco Transducer Products, Chatsworth, CA) was attached to the barbell to track position (9). The system was calibrated before and after each test session. All data were collected at a sampling frequency of 600 Hz.

Dependent variables including JH, PP_{CON}, PF_{CON}, PV_{CON}, PF_{ECC}, eccentric peak velocity (PV_{ECC}), concentric contact time ($Time_{CON}$), and eccentric contact time ($Time_{ECC}$) were calculated and obtained from the BMS software. Sheppard et al. (29) reported intraclass correlation coefficient ranging 0.71–0.95 for peak distance, 0.80–0.90 for peak power, 0.95–0.97 for peak force, and 0.75–0.83 for peak velocity. $IMP50ms_{ECC}$ values were collected according to Hori et al. (14) and Humphries et al. (15) as the area under the VGRF curve during the first 50 milliseconds after the point of landing.

WJS was divided into 2 phases, i.e., eccentric and concentric. The eccentric phase began when the subjects landed on the force platform that was defined as VGRF increasing 10N above zero. The eccentric phase ended when the velocity of the barbell became zero. This point was also defined as the beginning of the concentric phase. The concentric phase ended when the VGRF output first reached zero, i.e., takeoff (5). Following Hori et al. (14) dependent variables were collected from the set that provided the greater PP_{CON}. PP_{CON} was taken from the maximum of average peak power of the second jump to the sixth jump of each set.

Table 2
Counterbalancing of the 4 conditions evaluated.*

	Session 1	Session 2	Session 3	Session 4	Session 5	Session 6
Group 1	Pretest	Familiarization	B0	B25	B50	B100R
Group 2	Pretest	Familiarization	B25	B50	B100R	B0
Group 3	Pretest	Familiarization	B50	B100R	B0	B25
Group 4	Pretest	Familiarization	B100R	B0	B25	B50

*B0 = traditional load; B25 = 25% reduction in load for the downward phase; B50 = 50% reduction in load for the downward phase; B100R = 100% reduction in load for the downward phase with release on ground contact.

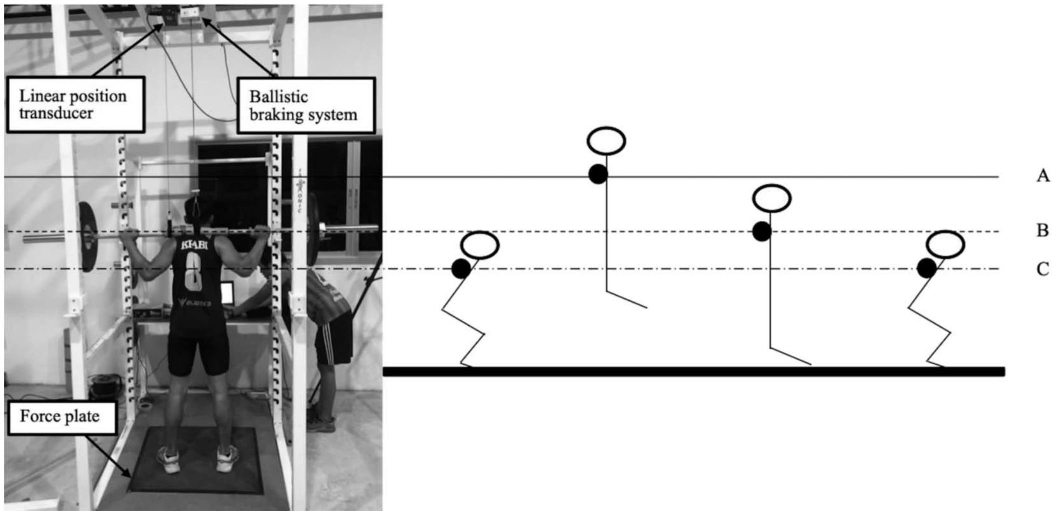

Figure 1. Equipment setup including position of the barbell for which line A represents the maximum jump height, line B represents the zero position (ground contact), and line C represents the lowest height (depth of countermovement).

Statistical Analyses

Data are reported as mean (±*SD*) and were analyzed using SPSS statistical software for Windows (version 23.0; SPSS Inc., Chicago, IL). Each dependent variable was compared using one-way repeated measures ANOVA with Bonferroni post hoc comparisons to determine whether there were significant differences between each condition. The level of significance was set at $p \leq 0.05$. Data were screened for sphericity using Mauchly's test. If the assumption of sphericity was violated, a Greenhouse-Geisser correction was used. Effect sizes (ESs) with 95% confidence interval (CI) of a pairwise comparison for each dependent variable were calculated following Cohen's *d* statistic. The criteria for interpreting the magnitude of the Cohen's *d* effect size were <0.2 trivial, 0.2–0.6 small, 0.6–1.2 moderate, 1.2–2.0 large, and >2.0 very large (13).

Results

Mean and standard deviations of the dependent variables and results of the one-way ANOVA with repeated measures are reported in Table 3. For the eccentric phase, the average JH of B0 was statistically lower than B25 ($p < 0.001$, ES = −1.33 [95% CI: −1.89 to −0.74]), B50 ($p < 0.001$, ES = −1.44 [95% CI: −2.04 to −0.83]), and B100R ($p < 0.001$, ES = −1.49 [95% CI: −2.10 to −0.87]). The average PF_{ECC} of B100R was lower than B0 ($p < 0.001$, ES = −0.59 [95% CI: −1.04 to −0.13]) and B25 ($p = 0.027$, ES = −0.29 [95% CI: −0.71 to 0.14]), but not statistically different compared with B50. The average PV_{ECC} of B0 was significantly lower (greater negative magnitude) than B50 ($p = 0.005$, ES = −0.41 [95% CI: −0.84 to 0.03]). The average $Time_{ECC}$ of all 4 conditions was significantly different ($p = 0.025$). However, we found no statistical difference between pairwise comparisons when tested using Bonferroni. The average $IMP50ms_{ECC}$ of B100R was lower than B0 ($p < 0.001$, ES = −0.92 [95% CI: −1.41 to −0.41]), B25 ($p = 0.005$, ES = −0.59 [95% CI: −1.04 to −0.13]), and B50 ($p = 0.001$, ES = −0.43 [95% CI: −0.86 to 0.01]). The average $IMP50ms_{ECC}$ of B50 was lower than B0 ($p = 0.017$, ES = −0.51 [95% CI: −0.94 to −0.06]).

For the concentric phase, the average PP_{CON} of B0 was statistically lower than B25 ($p = 0.029$, ES = −0.23 [95% CI: −0.66 to 0.19]), B50 ($p < 0.001$, ES = −0.35 [95% CI: −0.78 to 0.09]), and B100R ($p < 0.001$, ES = −0.39 [95% CI: −0.82 to 0.05]). The average PF_{CON} of B0 was statistically greater than B25 ($p = 0.041$, ES = 0.11 [95% CI: −0.31 to 0.53]), but there was no statistical difference when compared to B50 and B100R. The average PV_{CON} of B0 was statistically lower than B25 ($p < 0.001$, ES = −0.82 [95% CI: −1.29 to −0.32]), B50 ($p < 0.001$, ES = −0.96 [95% CI: −1.46 to −0.44]), and B100R ($p < 0.001$, ES = −1.15 [95% CI: −1.68 to −0.60]). Moreover, the average PV_{CON} of B100R was statistically greater than B25 ($p = 0.025$, ES = 0.36 [95% CI: −0.07 to 0.79]). The average $Time_{CON}$ across the 4 conditions was significantly different ($p = 0.008$). However, no statistical difference between pairwise comparisons was found with the Bonferroni test. The post hoc and effect sizes of pairwise comparisons are reported in Table 4.

A representative graph of force against time for one subject across the 4 conditions is presented in Figure 2. It should be noted that under B0, B25, and B50 conditions, PF_{ECC} occurred at about the same time. However, PF_{ECC} under the B100R condition was delayed and was much lower than the other 3 conditions.

Discussion

The purpose of this study was to examine the effects on the eccentric and concentric phases of the WJS with different braking levels and releasing the brake at ground contact, returning the full load to the subject. Our goal was to balance impact force and injury risk while retaining an acceptable stimulus for improving force and power output. We hypothesized that WJS under the B100R condition would provide the lowest $IMP50ms_{ECC}$ but the greatest PP_{CON} when compared to other loading conditions. We will begin by discussing the eccentric phase that is the first stage of a countermovement jump before focusing on the concentric phase of the jump. Hence, this section will start with how WJS with brake release may reduce injury risk.

Regarding reducing injury risk, our hypothesis is supported because the B100R condition provided significantly lower $IMP50ms_{ECC}$ compared with the other loading conditions (B0,

Table 3
Mean ± *SD* values for each dependent variable across the 4 conditions.*†

Dependent variable	B0	B25	B50	B100R	*p*
	Condition				
PP_{CON} (W)	3,539.31 ± 664.49	3,711.33 ± 741.20‡	3,773.52 ± 675.39‡	3,831.67 ± 757.23‡	<0.001
JH (m)	0.12 ± 0.03	0.17 ± 0.03‡	0.17 ± 0.03‡	0.17 ± 0.03‡	<0.001
PF_{ECC} (N)	2,904.97 ± 729.40	2,744.86 ± 890.00	2,720.85 ± 833.36	2,481.70 ± 692.66‡§	<0.001
PF_{CON} (N)	2,120.99 ± 374.79	2,077.55 ± 380.81‡	2,088.78 ± 356.19	2,106.76 ± 405.67	0.036
PV_{ECC} ($m \cdot s^{-1}$)	1.73 ± 0.22	1.81 ± 0.17	1.82 ± 0.18‡	1.76 ± 0.18	0.010
PV_{CON} ($m \cdot s^{-1}$)	1.81 ± 0.17	1.95 ± 0.17‡	1.97 ± 0.16‡	2.01 ± 0.18‡§	<0.001
$Time_{ECC}$ (s)	0.42 ± 0.08	0.39 ± 0.07	0.37 ± 0.05	0.39 ± 0.07	0.025
$Time_{CON}$ (s)	0.37 ± 0.04	0.36 ± 0.05	0.35 ± 0.04	0.34 ± 0.05	0.008
$IMP50ms_{ECC}$ (Nm)	41.21 ± 9.82	38.08 ± 10.34	36.31 ± 9.55‡	32.05 ± 10.13‡§‖	<0.001

*B0 = traditional load; B25 = 25% reduction eccentric loading; B50 = 50% reduction eccentric loading; B100R = traditional load with shock reduction; PP_{CON} = concentric peak power; JH = jump height; PF_{ECC} = eccentric peak force; PF_{CON} = concentric peak force; PV_{ECC} = eccentric peak velocity; PV_{CON} = concentric peak velocity; $Time_{ECC}$ = eccentric contact time; $Time_{CON}$ = concentric contact time; $IMP50ms_{ECC}$ = impulse over the first 50 milliseconds.
†*n* = 22 subjects.
‡Significantly different when compared to B0 conditions at $p < 0.05$.
§Significantly different when compared to B25 conditions at $p < 0.05$.
‖Significantly different when compared to B50 conditions at $p < 0.05$.

B25, and B50). Moreover, the B100R condition provided statistically lower PF_{ECC} than the B0 and B25 conditions. These findings are consistent with the study by Humphries et al. (15) and Hori et al. (14) where applying braking to the downward phase effectively reduced the passive impact force during landing from a weighted jump. $IMP50ms_{ECC}$ and PF_{ECC} under the B100R condition were lowest when compared to the other conditions because 100% of the additional loading was removed until landing reducing peak negative velocity and momentum (8,15).

Importantly, JH, PV_{CON}, and PP_{CON} under B25, B50, and B100R conditions were significantly higher than the B0 condition. By controlling the landing momentum with the braking system, the subjects could tolerate the eccentric loading and likely were not inhibited in the stretch phase and subsequent concentric action (14,20,23). Although a higher JH and a greater subsequent negative velocity and momentum were produced in the down phase, the braking mechanism under the B100R condition did not allow the subjects to fall freely but rather the acceleration was somewhat less than $-9.81\ m \cdot s^{-1} \cdot s^{-1}$. The combined mass of the barbell and body was slowed down by the braking mechanism; hence, PV_{ECC} under the B100R condition was slowest, although JH under the B100R condition was highest. Interestingly, B50 provided significantly higher PV_{ECC} than the B0 condition but with significantly lower $IMP50ms_{ECC}$ when compared with B0. As a result, B50 loading could also be considered viable for reducing landing impulse and injury risk in WJS.

Regarding improving power output, although BRT has been demonstrated to be highly effective for increasing power output (23), controlling the impact forces and impulse of landing is problematic and carries risk of injury to athletes. The Golgi tendon organ (GTO) reflex plays a critical protective role being triggered when tendon force is excessive resulting in the inhibition of motor neurons innervating the stretched muscles while exciting the motor nerves of the antagonist muscles (18). The number of GTOs fired and thus the magnitude of inhibition increases as the muscle tension increases (10,34,41). Because PFECC and $IMP50ms_{ECC}$ under the B100R condition were lower than the other 3 conditions, there was likely much lower or negligible inhibition and thus the subsequent jump was performed with higher PV_{CON} and PP_{CON}.

However, it seems GTO inhibition was substantial for the B0 condition as evidenced by lower PV_{CON}, PP_{CON}, and JH of the subsequent jump compared with the B25, B50, and B100R conditions. This outcome corresponds to Walshe and Wilson (38) where greater impact force created a greater level of reflex inhibition resulting in poorer jump performance. Our finding

Table 4
Post hoc comparisons and effect sizes among the 4 testing conditions for each dependent variable.*†

Dependent variable	B0 and B25	B0 and B50	B0 and B100R	B100R and B25	B100R and B50	B25 and B50
	p_{Holm}, (effect sizes)					
PP_{CON} (W)	0.029 (−0.23)	<0.001 (−0.35)	<0.001 (−0.39)	0.160 (0.16)	1.000 (0.07)	0.627 (−0.08)
JH (m)	<0.001 (−1.33)	<0.001 (−1.44)	<0.001 (−1.49)	1.000 (0.09)	1.000 (−0.06)	1.000 (−0.15)
PF_{ECC} (N)	0.392 (0.18)	0.095 (0.22)	<0.001 (0.59)	0.027 (−0.29)	0.065 (−0.29)	1.000 (0.03)
PF_{CON} (N)	0.041 (0.11)	0.184 (0.08)	1.000 (0.03)	0.709 (0.07)	1.000 (0.04)	1.000 (−0.03)
PV_{ECC} ($m \cdot s^{-1}$)	0.054 (−0.39)	0.005 (−0.41)	1.000 (−0.15)	0.296 (−0.28)	0.304 (−0.31)	1.000 (−0.03)
PV_{CON} ($m \cdot s^{-1}$)	<0.001 (−0.82)	<0.001 (−0.96)	<0.001 (−1.15)	0.025 (0.36)	0.145 (0.25)	1.000 (−0.12)
$Time_{ECC}$ (s)	0.594 (0.38)	0.081 (0.61)	0.426 (0.42)	1.000 (−0.04)	1.000 (0.17)	1.000 (0.22)
$Time_{CON}$ (s)	1.000 (0.23)	0.053 (0.52)	0.089 (0.59)	0.403 (−0.33)	1.000 (−0.13)	0.364 (0.22)
$IMP50ms_{ECC}$ (Nm)	0.536 (0.31)	0.017 (0.51)	<0.001 (0.92)	0.005 (−0.59)	0.001 (−0.43)	0.660 (0.18)

*B0 = traditional load; B25 = 25% reduction in load for the downward phase; B50 = 50% reduction in load for the downward phase; B100R = 100% reduction in load for the downward phase with release on ground contact; PP_{CON} = concentric peak power; JH = jump height; PF_{ECC} = eccentric peak force; PF_{CON} = concentric peak force; PV_{ECC} = eccentric peak velocity; PV_{CON} = concentric peak velocity; $Time_{ECC}$ = eccentric contact time; $Time_{CON}$ = concentric contact time; $IMP50ms_{ECC}$ = impulse over the first 50 milliseconds.
†*n* = 22 subjects.

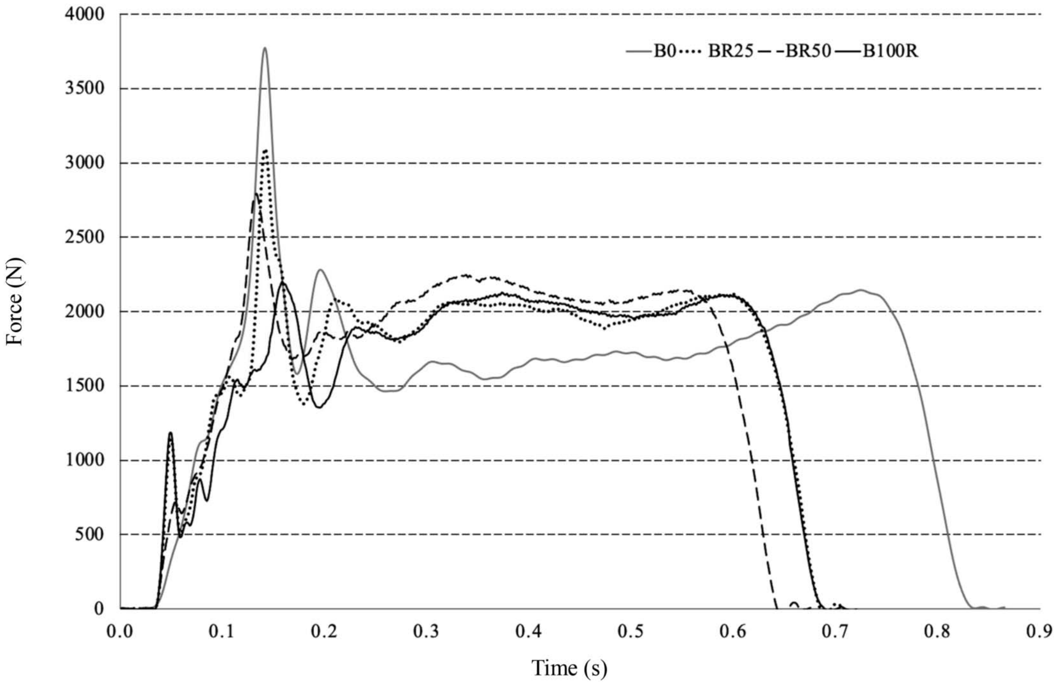

Figure 2. Force-time recordings of the ground contact phase across the 4 conditions for a single representative subject.

supports previous research where decrement in performance depended on the transition from eccentric phase to concentric phase that depends on physiological factors including reflex inhibition and stiffness regulation (5,10,28,34).

Several studies have emphasized the role of the eccentric phase in producing force and power in the concentric phase (5,12,30,41). In our study, the B100R condition produced the lowest $IMP50ms_{ECC}$ and PF_{ECC}, and therefore, activation of the GTO reflex was likely less than the other 3 conditions (10). However, braking under the B100R condition was applied differently to the other 3 conditions which were similar to Hoffman et al. (12) and Hori et al. (14). Rather than braking be applied for the total duration of the downward phase (from maximum JH to bottom of the countermovement), the braking system under the B100R condition was only applied from the peak of the jump to the point of ground contact and then released, returning the full load to the subject but without the large transient landing force firing the GTO reflex. With the full load now being applied, the muscles could contract maximally without inhibition or antagonist co-contraction and this produced greater impulse through the concentric phase resulting in the highest PV_{CON} and PP_{CON} (2,5,22,39). Whether this translates to more favorable training adaptations for increased velocity and power in ballistic movements requires further research.

In conclusion, eccentric loading during BRT affects strength and power production of lower extremity muscles as reported by several researchers (4,5,12,30). Findings of this study are that loading during landing affects force, velocity, and power output during the subsequent concentric phase because of the interplay of GTO reflex inhibition and optimizing the SSC. Determining the optimal eccentric loading condition is important (3). Too much impact load places the athlete at higher injury risk (15,27), but too little eccentric loading compromises force and power production and potentially development through chronic training. Eccentric loading with less than body mass has been reported to result in less muscle activity (24) and thus a negative effect on the concentric phase (25). Our results are that the B100R condition was most suitable for WJS training because PV_{CON} and PP_{CON} were significantly greater than the B0 condition but PF_{ECC} and $IMP50ms_{ECC}$ were significantly lower which should equate to higher probability of improving power development and reducing potential injury risk.

Practical Applications

Our findings emphasize the importance of eccentric loading conditions in WJS training to athletes and their strength and conditioning coaches. Although WJS has a great potential to develop strength and power, it has a high possibility of injuring athletes because of excessive landing impact. Reducing injury risk but allowing athletes to achieve high power production requires a balance of eccentric and concentric loading. We suggest that it is possible to reduce injury risk while maintaining power production during WJS by controlling accumulation of momentum during the free fall and then returning the barbell load to the athlete so they can make full use of the SSC. Therefore, strength and conditioning coaches should implement phases of WJS using landing impact reduction with releasing load strategies such as the B100R condition of the braking system investigated in this study. If such technology is not available, then caution should be used when performing WJS, perhaps using lighter than 30% additional load initially until adequate neuromuscular qualities are established.

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