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Title:	Power and impulse applied during push press exercise
Running Title:	Push press power and impulse

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Abstract: The aim of this study was to quantify the load that maximized peak and mean power, as well as impulse applied to these loads, during the push press and to compare them to equivalent jump squat data. Resistance-trained men performed two push press ($n = 17$; age: 25.4 ± 7.4 years; height: 183.4 ± 5 cm; body mass: 87 ± 15.6 kg) and jump squat ($n = 8$ of original 17; age: 28.7 ± 8.1 years; height: 184.3 ± 5.5 cm; mass: 98 ± 5.3 kg) singles with 10-90% of their push press and back squat 1 RM, respectively, in 10% 1 RM increments while standing on a force platform. Push press peak and mean power was maximized with 75.3 ± 16.4 and 64.7 ± 20% 1RM, respectively, and impulses applied to these loads were 243 ± 29 N.s and 231 ± 36 N.s. Increasing and decreasing load, from the load that maximized peak and mean power, by 10% and 20% 1RM reduced peak and mean power by 6-15% ($p < 0.05$). Push press and jump squat maximum peak power (7%, $p = 0.08$) and the impulse that was applied to the load that maximized peak (8%, p = 0.17) and mean (13%, p = 0.91) power were not significantly different, but push press maximum mean power was significantly greater than the jump squat equivalent (~9.5%, p = 0.03). The mechanical demand of the push press is comparable to the jump squat and could provide a time-efficient combination of lower-body power and upper-body and trunk strength training.

Keywords: Optimal-load; Force; Jump squat; Weightlifting; Load-power; ballistic

INTRODUCTION

Power training is often based around resistance exercise using the load that maximizes either peak instantaneous (4, 6, 20, 29) or mean propulsion (23, 28) phase power. It is believed that this load provides a resistance that optimizes both force applied to and velocity of the mass of interest, optimizing the ability to apply force quickly. Therefore, this load is often referred to as the optimal load. While early research reported considerable gains in both maximum strength and power in relatively untrained subject populations using a generic optimal loading strategy (23, 28), more recent research has prescribed optimal loads based on individual response to loading (6, 11, 20, 24, 29). An alternative approach is combined strength-power training, whereby the optimal load is combined with traditional heavy load training. Preliminary findings have shown that this combined approach is as effective as optimal load training for increasing lower-body power, improving both unloaded and loaded countermovement vertical jump power (4).

Traditionally, lower-body power training has focused on loaded countermovement vertical jump training (hereafter referred to as jump squat). Power is measured during jump squat with a spectrum of external loads (relative or absolute), providing a load-power relationship from which the optimal load can be identified (15). Some researchers have noted that there is potential for large impact forces during the landing phase of jump squat, which may expose athletes to an increased risk of overuse injury (13). However, while it is possible to use an electromagnetic braking device that controls barbell displacement during the landing phase (13), strength and conditioning coaches may not always have access to these. From a practical perspective therefore, it may be advantageous to identify resistance exercises that make a similar mechanical demand during the propulsion phase of the jump squat, but avoid the potentially problematic landing impact forces associated with it.

Common alternatives to traditional power resistance exercises, like the jump squat, are variations of the Olympic weight lifts, like power clean variants (2, 3, 15, 16), and kettlebell swing exercise (20, 21). Another potential alternative that is often included in strength and conditioning programs but has not received any research attention is the push press. This exercise resembles the jerk phase of the clean and jerk, beginning with the barbell in the 'rack' position across the anterior deltoids (18, 26). Lower-body countermovement then lowers the barbell-and-body system center of mass (CM) before the barbell is accelerated via rapid extension of the hips, knees and ankles, using an action similar to the jump squat, with the athlete locking out the arms overhead to complete the lift (26). Therefore, the push press combines the key components of loaded lower-body countermovement with overhead pressing without the potentially problematic forces associated with jump squat landing.

Although the push press has been included in athlete strength and conditioning programs (14), nothing is known about the power that is applied to the CM during its performance, meaning any contribution it might make to the power training process is unknown. Furthermore, the mechanical demand of this exercise, which can be quantified by studying the impulse applied to the CM, is unknown. Therefore, establishing the mechanical demand of the push press across a range of loads would enable strength and conditioning specialists to make informed decisions about the relative merits of the push press as an alternative lower-body power exercise to the jump squat. The aims of this study were to establish maximum peak and mean power, impulse applied to the load that maximized peak and mean power, the load that maximized peak and mean power during the push press, and to compare these data to equivalent data obtained from the loaded jump squat. Review of the literature led to the formulation of three hypotheses: 1) That push press peak and mean power would be maximized toward the heavier end of the load-power relationship (70 - 80% 1RM, 15, 16); 2) the load (relative to exercise 1 RM) that maximized push press peak and mean power would be significantly heavier than the load that maximized jump squat peak and mean power; and 3) that there would be no significant differences between push press and jump squat peak and mean power or the impulse applied to the load that maximized peak and mean power.

METHOD

Experimental approach to the problem

This study employed a within-subjects repeated measures design. Seventeen men who demonstrated competent push press technique attended a familiarization session, a push press 1 RM-testing session, and push press load-power testing session with 7 days between each. Eight of these subjects volunteered to return for the jump squat phase of this study. They demonstrated competent back squat and jump squat technique, and attended a familiarization session, a back squat-1 RM testing session, and a jump squat load-power testing session with 7 days between each. During load-power testing subjects performed 2 maximum effort single push presses and jump squats, on a force platform, with a range of loads. These began at 10% 1 RM, and increased in 10% 1 RM increments to 90% 1 RM, performed in that order and with 1-5 minutes rest between each set. Peak power, mean power and impulse were obtained from vertical GRF, and the load that maximized peak power and mean power, the optimal load, was identified on a subject-by-subject basis. The effect that increasing and decreasing load, from the load that maximized peak and mean power, by 10% and 20% 1 RM was established using *t* tests. This process was done for both push press and jump squat data. Maximum peak and mean power, impulse applied against the load that maximized peak and mean power, and the absolute and relative loads that maximized peak and mean power during the push press and jump squat were then compared using *t* tests.

Subjects

Seventeen healthy men (age: 25.4 ± 7.4 years; height: 183.4 ± 5 cm; body mass: 87 ± 15.6 kg; push press 1RM: 78 ± 13 kg) volunteered to participate. The institution's Ethical Review Board approved the investigation, and all subjects provided informed consent before participation. The study conformed to the principles of the World Medical Association's Declaration of Helsinki. Participant inclusion criteria required the demonstration of appropriate technique in each exercise from all subjects to a certified strength and conditioning specialist. None of the subjects were involved in competitive sport at the time of testing, but regularly included the push press in their training programs. Eight subjects (age: 28.7 ± 8.1 years; height: 184.3 ± 5.5 cm; mass: 98 ± 5.3 kg; push press 1RM: 86.7 ± 5.8 kg; back squat 1RM: 143.3 ± 15.3 kg), who were able to return for a second laboratory-based testing session did so 7 days later and performed loaded jump squat exercise.

Standardized warm-up

All subjects performed a standardized dynamic warm-up before all testing. This began with 5 minutes of easy stationary cycling, and was followed by 2-3 minutes of upper- and lower-body dynamic stretching. Specifically, subjects performed 2 circuits of 10 repetitions each of ‘arm swings’, ‘lunge walk’, ‘walking knee lift’, and ‘heel to toe lift’ (1). Warm up before push press testing included 2 sets of 5 sub-maximal (about 75% effort) push press repetitions with an empty 20 kg Olympic barbell. Warm up before jump squat testing included 2 sets of 5 sub-maximal (about 75% effort) jump squat repetitions with an empty 20 kg Olympic barbell.

Testing

Push press

Subjects attended at least 3 laboratory-based sessions with 7 days between each session. During the first session a certified strength and conditioning specialist established push press competency. During the second session a certified strength and conditioning specialist established push press 1 RM following the guidelines presented by Baechle *et al.* (Figure 15.1, page 396, (1)). During the third session subjects performed two single push presses with incremental loads, beginning with 10% of their pre-determined push press 1RM, increasing in 10% 1RM increments up to and including 90% 1RM.

Jump squat

Seven days later the 8 subjects who were able to return to the laboratory attended the first of their 3 jump squat specific sessions where a certified strength and conditioning specialist established back squat and jump squat competency. During the second session a certified strength and conditioning specialist established back squat 1 RM (1). During the third session subjects performed two single jump squats with incremental loads, beginning with 10% of their pre-determined back squat 1RM, increasing in 10% 1RM increments up to and including 90% 1RM. Subjects rested for a minimum of one minute and a maximum of five minutes between each repetition (25). All lifts were performed with subjects standing on a Kistler 9281 in-ground force platform (Kistler Instruments, Hook, United Kingdom) that recorded vertical GRF at

500 Hz, using Provec 5.0 software (Orthodata, Ludenschneid, Germany).

Data analysis

Data were analyzed using custom LabVIEW software (Version 10.0; National Instruments, Austin, TX, USA) to obtain the dependent variables of peak and mean power and impulse applied to the CM. Peak power was identified as the highest instantaneous value during the propulsion phase, while mean power was obtained by averaging power over the propulsion phase. Power was calculated as the product of force applied to and velocity of the CM. Velocity of the CM was obtained by subtracting barbell-and-body weight from vertical GRF before dividing it by barbell-and-body mass, and then integrating the product using the trapezoid rule. Impulse was obtained from the area under the net GRF-time curve (GRF minus barbell-and-body weight) during the propulsion phase using the trapezoid rule. The propulsion phase was identified from the velocity-time curve and began at the post countermovement transition from negative to positive velocity and ended at peak velocity (9, 19). The dependent variables demonstrated high within session test-retest reliability with intraclass correlation values between r = 0.902 and 0.970.

Statistical Analyses

The load that maximized peak and mean power, the optimal load, was identified on an individual-by-individual basis. Maximum peak and mean power, and impulse applied against the load that maximized peak and mean power were recorded and presented both in absolute and relative (power normalized to body mass, impulse normalized to system mass) terms. The effect that increasing and decreasing load, from the load that maximized peak and mean power, by 10% and 20% 1 RM had on peak and mean power was established using paired sample *t* tests (10). This process was then repeated with the jump squat data. Finally, maximum peak and mean power, impulse applied to the load that maximized peak and mean power, and the absolute and relative loads that maximized peak and mean power during push press and jump squat were then compared using paired sample *t* tests. All statistical analyses were performed using PASW (Version 20.0), and an alpha level of $p \leq 0.05$ was used to indicate statistical significance. Effect sizes (ES) were quantified using the scale recently presented by Hopkins *et al.* (12), where ES of 0.20, 0.60, 1.20, 2.0, and 4.0 represented small, moderate, large, very large and extremely large, effects respectively.

Insert Table 1 about here

Insert Figure 1 about here

RESULTS

Group mean (SD) (n = 17) push press load-peak power and load-mean power curves are presented in Figure 1. Results of the comparison of push press and jump squat load and mechanical demand characteristics (n = 8) are presented in Table 1. Push press peak power was maximized with a mean load of 75.3 ± 16.4% 1RM. The effect of increasing and decreasing load, from the load that maximized peak power, by 10% and 20% 1 RM resulted in significant reductions in peak power of between 6 and 13%, respectively. Push press mean power was maximized with a mean load of 64.7

± 20% 1 RM. The effect of increasing and decreasing load, from the load that maximized mean power, by 10% and 20% 1RM resulted in significant reductions in mean power of between 7 and 15%, respectively. The impulse applied to the load that maximized peak power was 242.6 ± 28.7 N.s, while the impulse applied to the load that maximized mean power was 230.9 ± 35.8 N.s.

Insert Figure 2, 3, 4 and 5 about here

Jump squat peak power was maximized with 52.5 ± 25.5% 1 RM, while mean power was maximized with 38.8 ± 34% 1 RM. The impulse applied to the load that maximized peak power was 278.7 ± 22.8 N.s, while the impulse applied to the load that maximized mean power was 256.9 ± 32.5 N.s. The effect of increasing and decreasing load, from the load that maximized peak power, by 10% and 20% 1 RM resulted in significant reductions in peak power of between 3 and 10%, respectively. Similarly, the effect of increasing and decreasing load, from the load that maximized mean power, by 10% and 20% 1 RM resulted in significant reductions in mean power of between 5 and 16%, respectively.

The effect that increasing and decreasing load, from the load that maximized peak and mean power, by 10% and 20% 1 RM had on push press peak and mean power is presented in Figures 2 and 3. Jump squat equivalents are presented in Figures 4 and 5. Jump squat maximum peak power was 6.7% greater than push press maximum peak power; this difference was not statistically significant ($p = 0.08$), but represented a moderate effect (ES = 0.59) (Table 1). Push press maximal mean power was 10.3%, and significantly greater ($p = 0.03$) than jump squat maximal mean power (ES = 0.81). The impulse applied during jump squat with the load that maximized peak power was significantly greater (14%, $p = 0.041$, ES = 1.08) than the push press equivalent, however there was no significant difference between the impulse applied during jump squat and push press with the load that maximized their respective mean powers (12%, $p = 0.252$), although the difference represented a moderate effect (ES = 0.61). There were no significant differences between normalized impulse applied during push press and jump squat with the load that maximized either peak or mean power (Table 1). There were no significant differences between the absolute barbell load that maximized jump squat and push press peak power ($p = 0.363$) and mean power ($p = 0.726$), although the jump squat load was 23 and 15% greater, respectively. Finally, jump squat propulsion phase duration was significantly longer than push press propulsion phase duration, with both maximum peak (41%, $p = 0.003$, ES = 4.31) and maximum mean power (32%, $p = 0.043$, ES = 2.26).

Insert Table 1 about here

DISCUSSION

The key findings of this study were that: 1) Peak power and mean power were maximized at different relative loads during the push press, and these tended to be larger, though not significantly, than their jump squat equivalents; 2) impulse applied to the load that maximized peak and mean power did not always represent the highest impulse recorded across the range of loads that were tested; 3) there were no significant differences between push press and jump squat maximum peak power (although a small to moderate effect size was recorded); 4) Push press maximum mean power was significantly greater than jump squat maximum mean power; and 5)

There were no significant differences between relative impulses applied during jump squat and push press. Therefore, push press training with the load that maximized peak and mean power could provide a stimulus sufficient to elicit a lower-body power training response.

To the authors' knowledge, this is the first study to establish the loads that maximized both peak and mean power during push press. These loads were very similar to those previously reported to maximize power in clean variants (2, 3, 15, 16), but were relatively heavy compared to the load that typically maximizes power during traditional lower-body power resistance exercises, like the jump squat (6, 20). These results, in conjunction with results presented by Kawamori *et al.* (15), suggest that variations of Olympic weightlifting exercises require a higher load because although ballistic, load projection must be performed under control and within technical constraints, which may prevent maximal power output with submaximal loads. For example, during performance of power clean variants the barbell must be controlled to enable the lifter to achieve a trajectory that will enable it to be caught in the rack position on the anterior deltoids. Similarly, the aim the 'ballistic lower-body' phase of the push press is to displace the barbell to a position that enables the athlete to complete the lift by pressing the barbell overhead from about eye level, although this position is easier to achieve with lighter loads. The barbell position at the conclusion of the power clean is the same as the push press start position (the anterior deltoid 'rack' position (18, 26)). Therefore, a power clean (from a hang position or from the floor) can be performed to position the barbell for the push press (26). This provides an additional power-training stimulus, and may provide a time efficient power-training resistance exercise that enables the application of relatively large peak and mean power outputs.

With regards to the impulse that was applied to the loads that maximized peak and mean power during push press, the results of this study demonstrate that the load-power and load-impulse relationship exist on different levels during push press. Knudson (17) recently reiterated that impulse, the product of force and time, is the mechanical parameter that determines both the magnitude and rate of motion of the object it is applied to, and that emphasis on power may be misleading. Although they were not reported, push press impulse was typically maximized with the heaviest load. In many ways, this should be expected because in exercises, like the push press, movement patterns and the time available to apply force are constrained. The resistance provided by the barbell-and-body must be displaced to a specific position to enable completion of the lift and extension of the duration of the active braking could compromise the availability of elastic energy. Therefore, barbell and body displacement and phase duration remains relatively consistent while the average force applied to the mass of the barbell-and-body must increase, constraining the load-impulse relationship. This is not necessarily the case during loaded (and unloaded) jump squat where displacement of the mass of the barbell-and-body varies across loading conditions, typically decreasing as load increases (10, 20). It would appear, therefore, that in exercises, like the push press, where movement patterns are constrained, power should remain the primary mechanical performance indicator to identify suitable power-training loads. However, future research into the interaction of the force and time components of impulse, and how they react to progressive loading during resistance exercises, like the push press may provide greater insight about the how parameters, like the rate of force development, influence performance and training outcomes. To the authors' knowledge, this is the first study to compare mechanical output data from the push press and jump squat, although other variations of the Olympic weight lifts have been compared to jump squat exercise (5, 27).

There was no significant difference between push press and jump squat maximum peak power, whether absolute or normalized relative to body mass. It is worth noting that peak power represents instantaneous power, and that because ground reaction force was recorded at a sampling frequency of 500 Hz it represents power applied over a 2 ms period. Peak power has been recorded from different resistance exercises extensively, and interest in this parameter may be largely attributed to the strong correlation between vertical jump peak power and jump height reported by Dowling and Vamos (7). They found that of the mechanical performance indicators recorded to predict vertical jump height, peak power was the strongest predictor. However, as noted by Knudson (17), the parameter that determines the magnitude and rate of motion is impulse. Dowling and Vamos (7) did not report impulse, and this seems to have shifted focus away from this important parameter. Although differences in push press and jump squat maximum peak power did not reach statistical significance, a moderate effect was recorded. Therefore, strength and conditioning coaches who use peak power as a way of prescribing power-training loads may prefer the jump squat to the push press.

In the present study mean power described the power applied to the CM during the propulsion phase, which was identified as beginning at the post countermovement transition from negative to positive velocity until peak velocity was achieve (22). The results of the present study showed that push press maximum mean power was significantly greater than jump squat maximum mean power, while push press propulsion lasted significantly longer than jump squat propulsion. However, the relevance of this finding depends on its eventual application (8). Dugan *et al.* (8) suggested that selection of the type of power output that is reported, whether peak instantaneous or averaged over a phase of interest, should be based on the one most closely related to the demands of the sporting task of interest. It could be argued that study of mean power could be more enlightening than study of power applied over a 2 ms (single sample) period because it considers interaction between the human and external mass interface over the phase or phases of interest. Impulse determines the magnitude and rate of motion (17). It might be reasonable to suggest that the focus of traditional power training should move toward improving the impulse that can be applied during a given sporting task related movement. The load that achieves this the most efficiently may correspond with the load that maximizes peak or mean power, but to the authors’ knowledge this area has not been researched and represents a significant gap in strength and conditioning knowledge.

Impulse is the product of force and time and in the current study was calculated as the area under the net force-time curve during the propulsion phase of each exercise. Absolute impulse applied against the load that maximized jump squat peak power was significantly greater than the push press equivalent. However, exercise cadence was not controlled, and this may have contributed to the significantly longer jump squat propulsion phase duration (see previous paragraph). Therefore, force was applied for significantly longer during the jump squat. This may have been a consequence of differences between key components of push press and jump squat countermovement technique, like depth, and requires further research attention. However, in addition to the longer duration over which force was applied during jump squat exercise, the absolute barbell load that was used must also be considered because, as explained above, as load increases so too must impulse. The relative loads that maximized jump squat peak and mean power were lighter, but the 1 RM that they were derived from was heavier, compared to the push press equivalents. Although differences in absolute barbell load did not reach statistical significance, because of relatively large between subject variance, absolute jump squat load was about 23% greater than absolute push press load. Interestingly, when impulse was normalized relative to combined barbell-and-body mass, differences decreased below statistical significance. Impulse normalized relative to the mass that it is applied to represents the velocity of that mass at the conclusion of the phase from which it was derived. In the present study this was the propulsion phase, and comparison revealed that although the velocity of the CM tended to be larger during the jump squat, differences did not reach statistical significance. Therefore, jump squat training with the load that maximizes peak power makes a significantly greater absolute mechanical demand on the lifter to yield a non-significant increase in peak power, while the push press enables the lifter to apply significantly greater power over the propulsion phase with less mechanical cost.

PRACTICAL APPLICATIONS

The results of this study indicate that the mechanical demands made during the propulsion phase of the push press could be sufficient to prescribe the exercise for lower-body power training in athlete strength and conditioning programs. Typically power is trained with the load that maximizes either peak or mean power. Furthermore, the initial aim of push press performance is to displace the barbell to a position that enables the athlete to lock the arms out with the barbell overhead, which may simultaneously provide a lower-body power training stimulus, an upper-body pressing stimulus, and a trunk stability training stimulus. Therefore, prescribing push press exercise with the load that maximizes power could provide a time-efficient combination of power and strength-training exercise, particularly if preceded by a power clean variant and incorporated into strength and conditioning programs that include a traditional-strength lower-body resistance exercise, like the back squat.

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FIGURE AND TABLE LEGENDS

Figure 1. Group mean (SD) push press load-peak power and mean power outputs (n = 17).

Figure 2. Load effect on maximum push press peak power (n = 8).

Figure 3. Load effect on maximum push press mean power (n = 8).

Figure 4. Load effect on maximum jump squat peak power (n = 8).

Figure 5. Load effect on maximum jump squat mean power (n = 8).

Table 1. Comparison of push press and jump squat load and mechanical demand characteristics (n = 8).

Table 1. Comparison of push press and jump squat load and mechanical demand characteristics (n = 8).

	PP (W)	PP (W.kg^{-1})	Load (% 1RM)	Load (kg)	MP (W)	MP (W.kg^{-1})	Load (% 1RM)	Load (kg)	J_{PP} (N.s)	J_{MP} (N.s)	J_{PP} (m.s^{-1})	J_{MP} (m.s^{-1})
Push press	3640.1	37.5	81.3	64.4	2313.6	23.8	63.8	52.5	247.8	233.9	1.53	1.55
	573.8	7.4	9.9	9.6	332.5	4.3	16.9	20.0	34.6	42.4	0.19	0.15
Jump squat	3885.2	39.9	52.5	78.8	2096.0	21.5	38.8	60.3	278.7	256.9	1.65	1.75
	302.3	4.6	25.5	42.7	201.8	2.8	34.0	59.2	22.8	32.5	0.33	0.38
% difference	-6.7	-6.4	30.3	-22.4	9.4*	9.7*	40.0	-14.9	-14.9	-11.3	-7.8	-12.9
Lower 95% confidence limit	-15.3	-15.3	1.7	-81.6	1.7	1.7	-5.2	-95.7	-27.0	-29.8	-18.77	-27.85
Upper 95% confidence limit	-0.4	-0.4	65.0	36.2	15.6	15.6	80.6	65.0	-0.9	5.0	4.06	3.79
Effect size	-0.56	-0.41	1.62	-0.55	0.81	0.64	0.98	-0.20	-1.08	-0.61	-0.46	-0.74

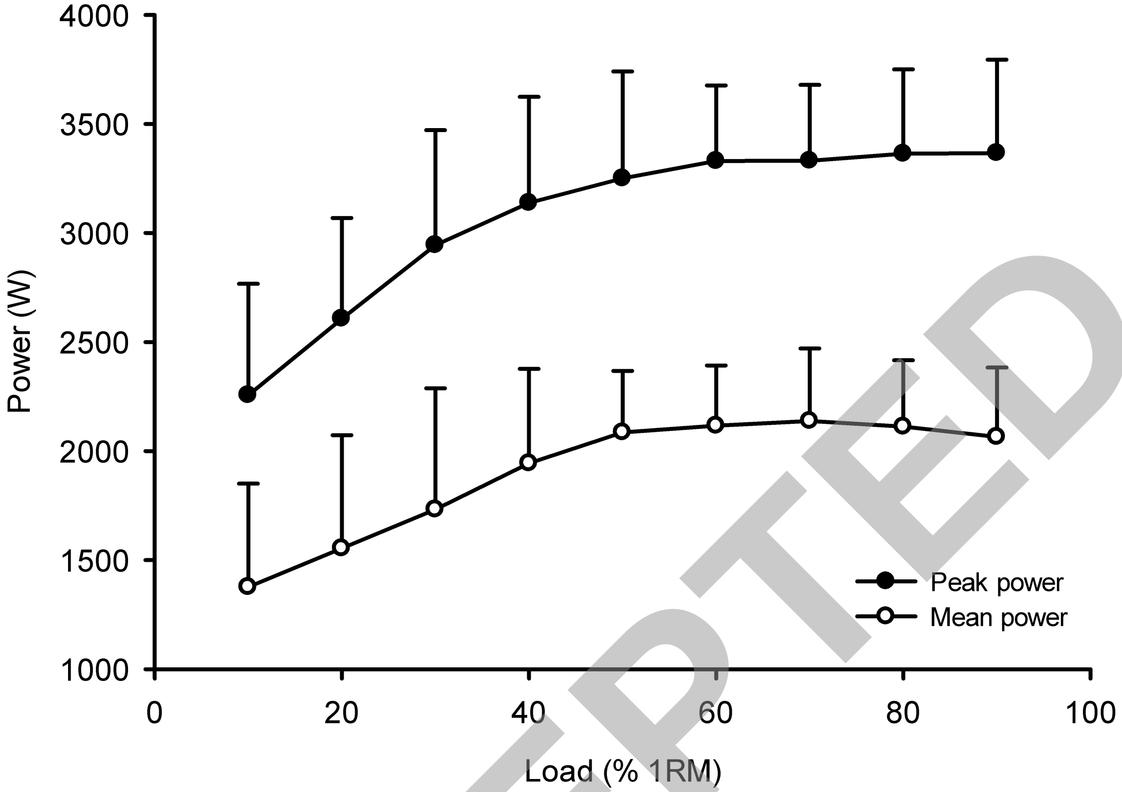
* = push press significantly different to jump squat

PP = maximum peak power

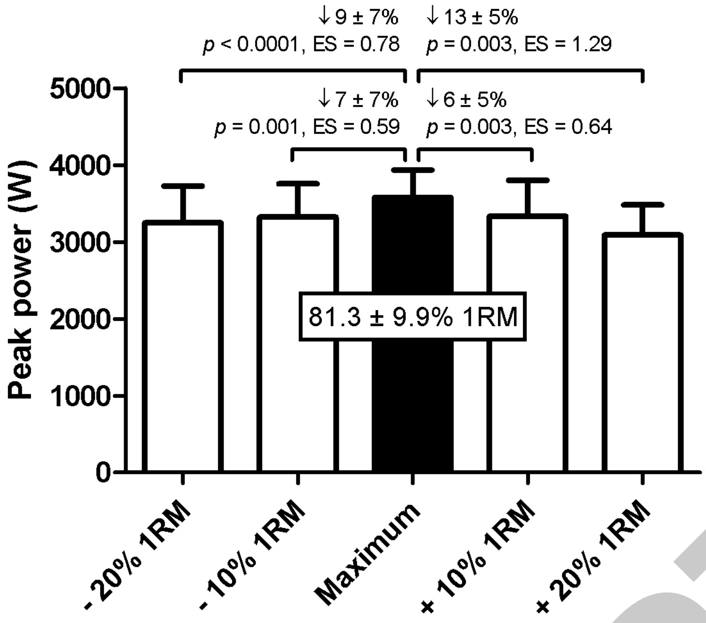
MP = maximum mean power

J_{PP} = impulse applied to the load that maximized peak power

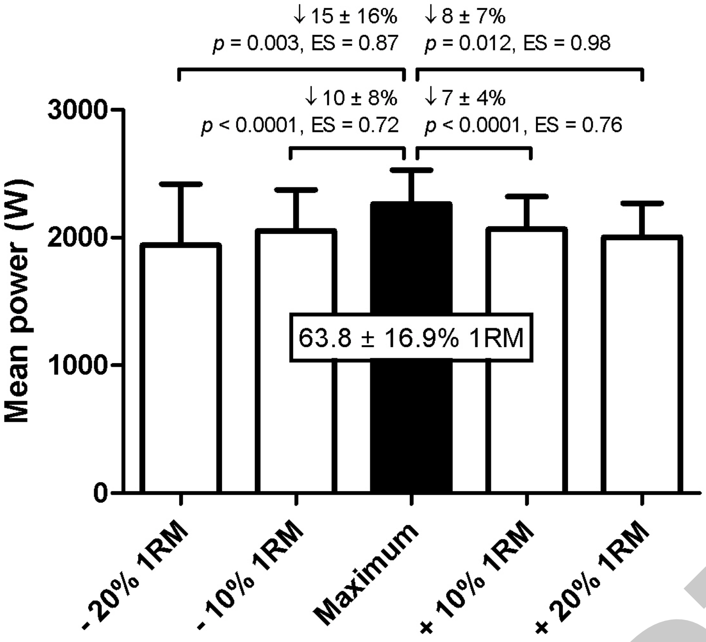
J_{MP} = impulse applied to the load that maximized mean power

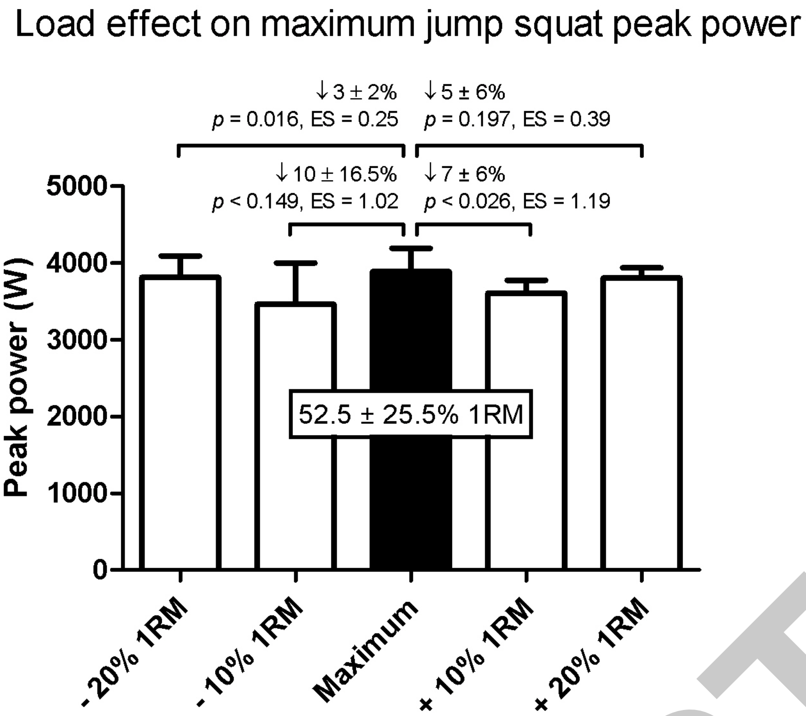

4000
3500
3000
2500
2000
1500
1000
Power (W)
0
20
40
60
80
100
Load (% 1RM)
Peak power
Mean power

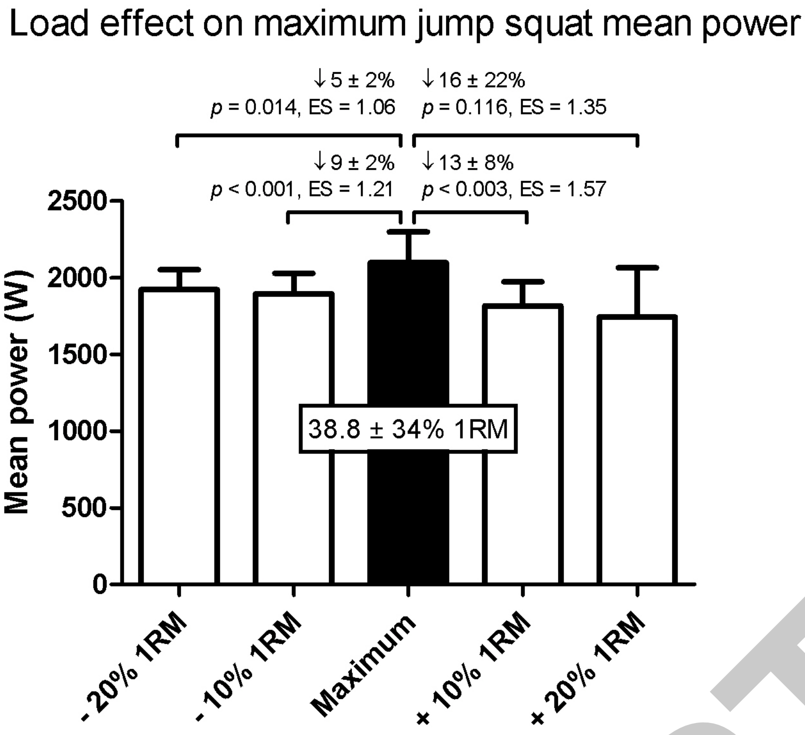
Load effect on maximum push press peak power



Load effect on maximum push press mean power




Load effect on maximum jump squat peak power
↓3 ± 2%
p = 0.016, ES = 0.25
↓5 ± 6%
p = 0.197, ES = 0.39
↓10 ± 16.5%
p < 0.149, ES = 1.02
↓7 ± 6%
p < 0.026, ES = 1.19
Peak power (W)
5000
4000
3000
2000
1000
0
52.5 ± 25.5% 1RM
- 20% 1RM
- 10% 1RM
Maximum
+ 10% 1RM
+ 20% 1RM


Load effect on maximum jump squat mean power
↓5 ± 2%
p = 0.014, ES = 1.06
↓16 ± 22%
p = 0.116, ES = 1.35
↓9 ± 2%
p < 0.001, ES = 1.21
↓13 ± 8%
p < 0.003, ES = 1.57
Mean power (W)
2500
2000
1500
1000
500
0
38.8 ± 34% 1RM
- 20% 1RM
- 10% 1RM
Maximum
+ 10% 1RM
+ 20% 1RM