

Research article

## Improved Maximum Strength, Vertical Jump and Sprint Performance after 8 Weeks of Jump Squat Training with Individualized Loads

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### Abstract

The purpose of the study was to determine the effects of 8 weeks of jump squat training on isometric half squat maximal force production (F<sub>max</sub>) and rate of force development over 100ms (RFD<sub>100</sub>), countermovement jump (CMJ) and squat jump (SJ) height, and 50 m sprint time in moderately trained men. Sixty eight subjects (~21 years, ~180 cm, ~75 kg) were divided into experimental (EXP; n = 36) and control (CON, n = 32) groups. Tests were completed pre-, mid- and post-training. EXP performed jump squat training 3 times per week using loads that allowed all repetitions to be performed with ≥90% of maximum average power output (13 sessions with 4 sets of 8 repetitions and 13 sessions with 8 sets of 4 repetitions). Subjects were given real-time feedback for every repetition during the training sessions. Significant improvements in F<sub>max</sub> from pre- to mid- (Δ ~14%, p<0.001), and from mid- to post-training (Δ ~4%, p < 0.001) in EXP were observed. In CON significantly enhanced F<sub>max</sub> from pre- to mid-training (Δ ~3.5%, p < 0.05) was recorded, but no other significant changes were observed in any other test. In RFD<sub>100</sub> significant improvements from pre- to mid-training (Δ ~27%, p < 0.001), as well as from mid- to post-training (Δ ~17%, p < 0.01) were observed. CMJ and SJ height were significantly enhanced from pre- to mid-training (Δ ~10%, ~15%, respectively, p < 0.001) but no further changes occurred from mid- to post-training. Significant improvements in 50 m sprint time from pre- to mid-training (Δ -1%, p < 0.05), and from mid- to post-training (Δ -1.9%, p < 0.001) in EXP were observed. Furthermore, percent changes in EXP were greater than changes in CON during training. It appears that using jump squats with loads that allow repetitions to be performed ≥90% of maximum average power output can simultaneously improve several different athletic performance tasks in the short-term.

**Key words:** Real-time feedback, power, strength, explosive training, ballistic training.

### Introduction

There are a variety of strength training methods that are used to develop athletic performance, such as sprinting and jumping. These methods include; 1) heavy strength / hypertrophic training, 2) plyometric training and 3) explosive weight / power training using various loads associated with different parts of the power-velocity curve. Heavy strength training typically induces increases in maximum force production and muscle mass (Chelly et al., 2009; Cormie et al., 2010; Häkkinen, 1989; Sale, 1988; Tesch, 1989; Wilson et al., 1993), while plyometric training

primarily increases rapid force production (Impellizzeri et al., 2008; Matavulj et al., 2001; Markovic et al., 2007). Explosive weight training may be considered as a hybrid of these two methods as it has been shown to develop all of these aspects of neuromuscular performance (Cormie et al., 2010; Harris et al., 2008; Lamas et al., 2012; McBride et al., 2002; Winchester et al., 2008).

One example of explosive weight training that has been the focus of several research papers is the jump squat exercise. Here, a loaded bar is held on the shoulders and the individual squats down prior to rapidly extending the legs and torso to finally leave contact with the floor. The load used during jump squat training seems to be an important consideration for training outcomes. Following the law of specificity, training with lighter loads improves power at the high velocity end of the force-velocity curve, whereas higher loads improves power at the high force end of the force-velocity curve (McBride et al., 2002; Smilios et al., 2013).

However, the efficacy of jump squat training to simultaneously improve different athletic performance remains an element of contention within the literature. For example, use of light load jump squat training (e.g. 0-30% 1-RM load) has not led to improved maximum strength in some studies (Cormie et al., 2010; Wilson et al., 1993). Conversely, heavy load jump squat training (e.g. 60-90% 1-RM) has been shown to be ineffective in improving countermovement jump performance/rapid force production (Newton et al., 1999). The above examples have used fixed loading protocols that were determined as a percentage of maximum squat performance (i.e. 1-RM) without assessing the individual's power curve during the jump squat.

In studies where the load that maximizes mean power output (calculated without the inclusion of body mass) has been calculated there seems to have been more consistent simultaneous improvement in maximum and rapid force production, as well as sprint and jump performance (Lamas et al., 2012; Newton et al., 1999; Smilios et al., 2013; Wilson et al., 1993). Nevertheless, use of loads that maximize mean power output has not been studied in depth. Given that maximum mean power output may shift slightly during training with different loading schemes (McBride et al. 2002; Smilios et al., 2013), it may be pertinent to assess what load maximizes power output and train according to that load in order to develop global improvements in neuromuscular performance.

Furthermore, due to the use of; 1) different training protocols, 2) different test protocols, 3) different subject training background (i.e. trained and untrained), and 4) low sample sizes used in the literature, it is not certain whether jump squat power training with individualized loads can indeed lead to simultaneous improvements in several athletic performance tests. Consequently, the purpose of the present study is to determine whether jump squat power training with individualized loads can simultaneously improve maximum strength, rapid force production, as well as vertical jump and sprint performance using a large cohort of physically active men.

## Methods

### Study design

Healthy, young men performed 8 weeks of loaded jump squat training. During training, each repetition was monitored and real-time feedback provided to the subjects to ensure maximum effort and appropriate termination of the set. The subjects were tested for maximal isometric squat strength, vertical jump performance and maximum sprinting speed pre-, mid- (after 4 weeks), and post-training (after 8 weeks). The tests were performed on 2 separate occasions, the first test day included countermovement jump (CMJ), squat jump (SJ) and the jump squat diagnostic series (described below). On the second day of testing, subjects performed isometric half squat and 50m sprint trials. Prior to all test sessions a standardized warm-up was performed consisting of 5 min jogging followed by 5 min dynamic stretching. Before the vertical jump tests the subjects performed 2 sets and 8 reps of jump squats (body weight only) separated by 1 minute of rest. Isometric testing was preceded by 2 submaximal trials over duration of approx. 4 seconds separated by 2 minutes of rest. Maximal running speed (50 m) was preceded by two 50 m sprints with submaximal effort.

### Subjects

Sixty eight male students of the Faculty of Physical Education and Sport completed the study (age  $21.9 \pm 2.5$  years, body height  $1.80 \pm 0.06$  m, and body weight  $75.3 \pm 9.5$  kg). Subjects were moderately trained athletes with at least 2 years' experience in strength training. After being fully informed on all possible risks and discomfort they signed an informed consent form. The University's ethical committee approved this study, which was carried out according to the Declaration of Helsinki. At the beginning of the study subjects were pair-matched and randomly divided into the experimental group (EXP;  $n = 40$ ) and the control group (CON;  $n = 40$ ). However, due to drop-outs (e.g. unrelated injuries, non-attendance in training, failing to attend test sessions) the final sample size included in this study was 36 in the experimental group and 32 in the control group.

### Familiarization session

As part of the study, subjects completed a familiarization session. Subjects were informed about the correct (unloaded and loaded) jump squat technique. Each subject practiced this exercise and was subsequently instructed

through a strength training specialist how to improve their individual technique. All subjects were familiar with the devices used in the study, as well as with the measurement methodology.

### Determination of the load that maximizes average power output - diagnostic series

Before the start of the experiment, subjects performed a diagnostic series of jump squats with maximal effort in the concentric phase of the movement. During the jump squat, each subject squatted down to a knee angle of approx.  $90^\circ$  ( $180^\circ =$  full extension), which was controlled through the use of foam cubes, while supporting the barbell on the shoulders (Vanderka et al. 2016). The instructions for subjects were as follows: squat down in a controlled manner and then immediately jump straight up as quickly as possible. The series consisted of two trials with each load and gradually increased in 10 kg steps with 3 min rest between trials. The external load began with 20 kg (i.e. bar only) and the test was terminated upon reaching a plateau (or even decrease) in maximum average power output (Pmax). To confirm this finding, each participant performed 2 attempts above the Pmax load (+20 kg) as a control measurement.

### Determination of the number of repetitions above 90% of maximum power output - pilot study

Based on findings of Baker and Newton (2007), who stated that maintaining power output of >90% maximum power output was possible for 2-3 repetitions with 45-60% 1-RM (full squat) and 5-6 repetitions with 35% 1-RM, it was important to determine how many repetitions would be possible with the chosen loads in the present study. Therefore, one week before pre-training measurements, a sub-set of the subjects ( $n = 20$ ; age  $21.5 \pm 1.4$  years; body height  $1.78 \pm 0.02$  m; body weight  $75.3 \pm 8.7$  kg) were randomly chosen to perform 1 set with Pmax load and 1 set with a lighter load corresponding to 90% of maximum power output (approx. 80% Pmax load according to the diagnostic series described above). The subjects performed these loading sets in a counterbalanced, cross-over design. The subjects were instructed to jump as high as possible until the power output fell below 90% of the highest power output (typically rep 2 or 3) of the set. The subjects could perform, on average,  $8.3 \pm 2.8$  repetitions maintaining the power output above 90% with lighter external load, and  $4.4 \pm 1.5$  repetitions with Pmax load. The determined load and repetition series formed the basis of our training program.

### Training protocol

EXP trained 3 times per week for 8 weeks. The intensity of each jump squat repetition was recorded by the linear displacement transducer (FiTRO Dyne Premium, FiTRONiC Diagnostic and Training Systems LTD, Bratislava, Slovakia) and displayed in real-time to the subject to ensure motivation and maximum effort. The FiTRO Dyne device was attached to the barbell perpendicular to the floor through a nylon cord. The system's sensor unit is connected to a computer with matching software that gives feedback regarding force, velocity and power. It

has been shown to be a reliable device to measure power (Jennings et al., 2005). In the same way as during the diagnostic series, the squat depth (approx. 90° knee angle) was controlled by foam cubes, which were 10 cm in width and individually adjusted for each subject. All subjects squatted down until the hamstrings touched the foam cubes and then jumped as high as possible. The subjects performed a total of 26 training sessions during the 8-week period. Thirteen training sessions were performed using 8 sets of 4 repetitions with Pmax load and 13 sessions were performed using 4 sets of 8 repetitions with 80% of Pmax load. Three minutes rest was given between each set in all sessions. CON maintained their normal physical activity, but they were instructed not to perform any organized heavy strength and explosive power training during the 8-week period.

### Measurement of half squat isometric maximal force production and rate of force development

To assess maximal isometric half squat force (Fmax) and rate of force development (RFD), a modified smith-machine was used with subjects standing on a dynamometric FiTRO Force Plate (FiTRONiC Diagnostic and Training Systems LTD, Bratislava, Slovakia). The system consists of a strain gauge force plate connected to a pc via a 12-bit AD convertor and uses customized software to calculate vertical forces acting on the force platform (sampling frequency was 1000 Hz). The force platform was calibrated and zeroed before each measurement session during the study. The barbell was placed on the racks and was individually adjusted so that the subject's knee angle was 90° during the half squat. Each subject was instructed to push "as hard and as fast as possible". Subjects performed 2 trials over duration of 5 seconds. A rest interval of 3 min was given between trials. Fmax and RFD were analyzed from the same trial, with the highest Fmax value determining the best performance. Evaluated parameters were Fmax (N) and average RFD ( $N \cdot ms^{-1}$ ) over time intervals of 0-50ms, 0-100ms (RFD<sub>100</sub>), 0-150ms. Since the findings were similar for RFD over 50 and 150ms, data presented here will be limited to 0-100ms. Fmax was normalized to body mass in each time period. Intra-class correlation coefficient (ICC) test-retest reliability during the pilot study was 0.94 for Fmax and 0.90 for RFD<sub>100</sub>.

### Vertical jumping measurement

Countermovement and squat jump height was measured via a Myotest accelerometer system (Myotest® Performance Measuring system, Sion, Switzerland). The device calculates jump height through change in position in the vertical plane (2D accelerometer with sampling frequency of 500 Hz). The device was placed on a stick, which was held on the shoulders (similar to barbell jump squats) and all subjects were informed to avoid any involuntary movement in the vertical plane during jumps that could affect jump height. The Myotest device has been shown to be valid and reliable to measure CMJ (ICC = 0.96) and SJ height (ICC = 0.92) (Casartelli et al., 2010).

During the session, subjects performed 2 trials of squat jump from a 90° knee joint angle. They were instructed to avoid any countermovement in this position to

eliminate utilization of elastic energy. Similarly, two trials were performed for the CMJ and subjects were instructed to perform CMJ test to a self-selected depth. During both tests the subjects were instructed to jump "as high as possible". Rest intervals between trials were approx. 30-60 seconds and the highest jump was recorded for further analysis.

### Maximal running speed measurement

To evaluate maximal running speed over a distance of 50 m dual-beam light timing gates were used (Vanel-gates, Vanel Ltd, Nizna, Slovakia). Subjects began from a stationary, standing start where the front foot was placed 50 cm behind the first timing gate. This distance (i.e. -0.5 m) was chosen to avoid spontaneous triggering of the timing gates (i.e. arm wave).

All subjects performed 2 trials and ran as fast as possible throughout the entire 50 m distance. The rest interval between trials was 5 minutes. The best time was recorded for later analysis. ICC test-retest reliability for 50 m sprint time was 0.98.

### Statistical analysis

Standard methods were used to determine means and standard deviations. Main effects for time, group and time×group were assessed by analysis of covariance (ANCOVA) with repeated measures using baseline values as covariates. Bonferroni post-hoc tests were used to detect where the significance differences occurred. Differences between groups in relative changes ( $\Delta\%$ ) over time were assessed by independent T-test. Cohen's *d* effect sizes were calculated and interpreted as < 0.2 is a small, 0.2-0.8 is a moderate, and > 0.8 is a large effect. Pearson product-moment correlation analysis (*r*) was used to determine the relationship between variables. 95% confidence intervals (95% CI) were also calculated. Statistical assumptions for each dependent variable were performed using the Shapiro-Wilk test and all data were normally distributed. All descriptive statistics and statistical methods were performed using IBM SPSS 22 and data is presented as uncorrected for covariate. Alpha was set at ≤ 0.05.

## Results

### Half squat isometric maximal force production and rate of force development

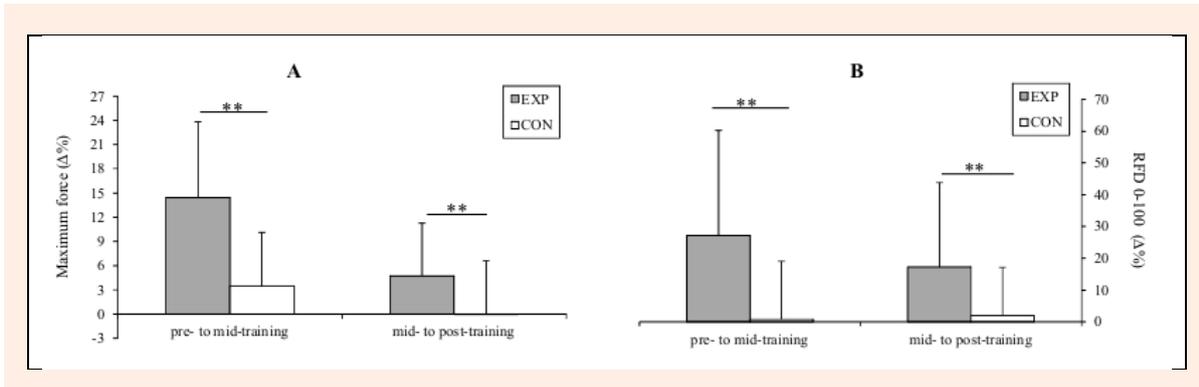
In Fmax, significant main effects for time×group ( $F = 21.63$ ,  $p < 0.001$ ) and time ( $F = 5.91$ ,  $p < 0.01$ ) were observed. EXP increased significantly from pre- to mid-training ( $p < 0.001$ ,  $d = 0.89$ , 95% CI = 2.65 to 4.61  $N \cdot kg^{-1}$ ), as well as from mid- to post-training ( $p < 0.001$ ,  $d = 0.32$ , 95% CI = 0.54 to 2.18  $N \cdot kg^{-1}$ ). Also, CON significantly increased from pre- to mid-training only ( $p = 0.02$ ,  $d = 0.32$ , 95% CI = 0.11 to 1.66  $N \cdot kg^{-1}$ , Table 1). Percentage changes between groups were significantly different from pre- to mid-training (14.4% [EXP] vs. 3.5% [CON],  $T = 5.43$ ,  $p < 0.001$ , 95% CI = 6.9 to 15.0%), as well as from mid- to post-training (4.7% [EXP] vs. -0.1% [CON],  $T = 2.94$ ,  $p = 0.004$ , 95% CI = 1.5 to 8.0%) for Fmax (Figure 1A).

For RFD<sub>100</sub>, a significant time×group interaction

**Table 1. Neuromuscular performance during the 8-week study period. Values are means ( $\pm$ SD).**

	EXP			CON		
	pre	mid	post	pre	mid	post
<b>Fmax (<math>N \cdot kg^{-1}</math>)</b>	26.1 (4.1)	29.7 (4.1)**†	31 (4.1)**§	26.5 (2.6)	27.4 (2.9)*†	27.3 (3.2)
<b>RFD<sub>100</sub> (<math>N \cdot ms^{-1}</math>)</b>	4.3 (1.6)	5.2 (1.6)**†	5.9 (1.4)**§	4.5 (1.5)	4.4 (1.5)	4.5 (1.4)
<b>CMJ (cm)</b>	45.1 (5.5)	49.4 (5.9)**†	50.4 (6.2)	46.8 (7.1)	46.6 (7.1)	47.2 (7.4)
<b>SJ (cm)</b>	39.3 (5.1)	45.3 (6.3)**†	45.4 (6.4)	41.3 (6.5)	40.6 (6.4)	41.8 (6.2)
<b>50 m sprint (s)</b>	6.58 (0.28)	6.51 (0.29)*†	6.39 (0.24)**§	6.57 (0.25)	6.6 (0.31)	6.58 (0.31)

\* indicates significant difference ( $p < 0.05$ ); \*\* indicates significant difference ( $p < 0.01$ ); † indicates significant difference between pre- to mid; § indicates significant difference between mid- to post; EXP (experimental group); CON (control group); pre (pre-training); mid (mid-training); post (post-training)



**Figure 1. Percentage change (mean  $\pm$ SD) in maximum force (A) and rate of force development (B) performance in the experimental and control groups during the 8-week study period. \*\*  $p < 0.01$ . EXP = experimental group, CON = control.**

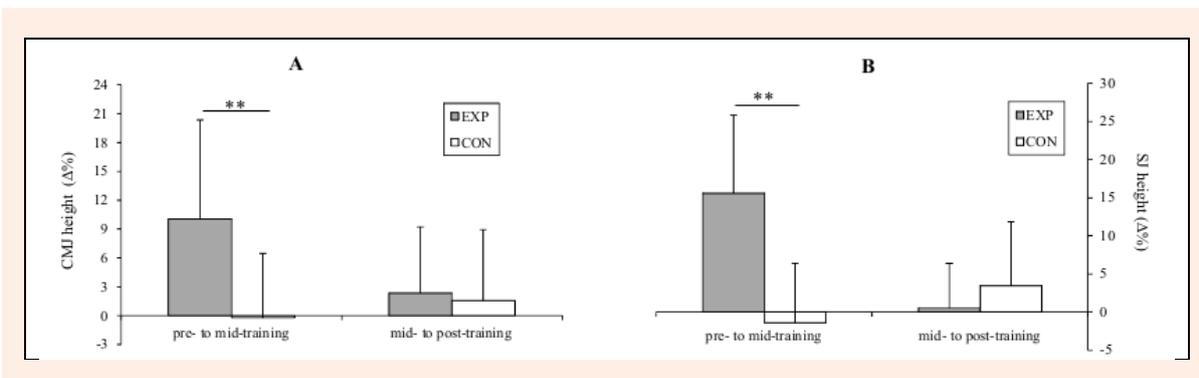
was observed ( $F = 20.48, p < 0.001$ ) as well as for time ( $F = 18.37, p < 0.001$ ). EXP increased significantly from pre- to mid-training ( $p < 0.001, d = 0.55, 95\% \text{ CI} = 0.509$  to  $1.24 \text{ N} \cdot \text{ms}^{-1}$ ), and from mid- to post-training ( $p < 0.001, d = 0.42, 95\% \text{ CI} = 0.32$  to  $0.94 \text{ N} \cdot \text{ms}^{-1}$ ). No significant differences in CON were observed (Table 1). Percentage changes between groups were significantly different from pre- to mid-training (27.2% [EXP] vs. 0.8% [CON],  $T = 3.95, p < 0.001, 95\% \text{ CI} = 13.1$  to  $39.7\%$ ) and from mid- to post-training (17.2% [EXP] vs. 2% [CON],  $T = 2.81, p = 0.005, 95\% \text{ CI} = 4.4$  to  $26.1\%$ ) for RFD<sub>100</sub> (Figure 1B).

**Vertical jump performance**

In the CMJ, a significant time $\times$ group interaction was observed ( $F = 16.1, p < 0.001$ ), as well as a significant effect for time ( $F = 4.03, p = 0.024$ ). Post hoc tests revealed that EXP increased significantly from pre- to mid-training ( $p < 0.001, d = 0.75, 95\% \text{ CI} = 2.7$  to  $5.9 \text{ cm}$ ) but

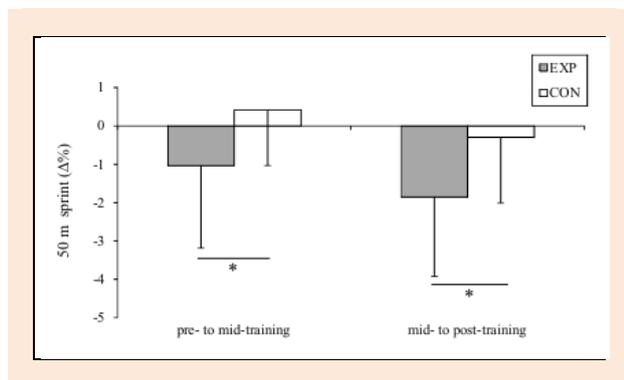
no significant differences were observed between mid- to post-training ( $p > 0.05, 95\%, d = 0.18, \text{CI} = -2.48$  to  $0.35 \text{ cm}$ ). There were no significant changes between pre- to mid-training or mid- to post-training in CON for CMJ (Table 1). Percentage changes between groups were significantly different from pre- to mid-training (10% [EXP] vs. -0.3% [CON],  $T = 4.81, p < 0.001, 95\% \text{ CI} = 6.0$  to  $14.6\%$ ) for CMJ. No significant changes between both groups occurred from mid- to post-training (Figure 2A).

In the SJ, a significant time $\times$ group interaction was observed ( $F = 36.46, p < 0.001$ ), as well as a significant effect for time ( $F = 3.21, p = 0.047$ ). EXP increased significantly from pre- to mid-training ( $p < 0.001, d = 1.04, 95\% \text{ CI} = 4.4$  to  $7.6 \text{ cm}$ ) but no significant differences ( $p > 0.05, d = 0.02, 95\% \text{ CI} = -1.7$  to  $1.4 \text{ cm}$ ) between mid- to post-training were observed. There were no significant changes between pre- to mid-training or mid- to post-training in CON for SJ (Table 1). Percentage changes between groups were significantly different from



**Figure 2. Percentage change (mean  $\pm$ SD) in countermovement (A) and squat (B) jump performance in the experimental and control groups during the 8-week study period. \*\*  $p < 0.01$ . EXP = experimental group, CON = control.**

pre- to mid-training (15.6% [EXP] vs. -1.4% [CON],  $T = 8.21$ ,  $p < 0.001$ , 95% CI = 12.8 to 21.1%) for SJ (Figure 2B).



**Figure 3.** Percentage change (mean  $\pm$ SD) in 50 m sprint performance in the experimental and control groups during the 8-week study period. \*\* =  $P < 0.01$ ; \* =  $P < 0.05$ . EXP = experimental group, CON = control.

### Maximal running speed

In 50 m sprint time, a significant time  $\times$  group interaction was observed ( $F = 17.73$ ,  $p < 0.001$ ). EXP significantly decreased their sprint time from pre- to mid-training ( $p = 0.02$ ,  $d = 0.24$ , 95% CI = -0.01 to -0.13 s), as well as from mid- to post-training ( $p < 0.001$ ,  $d = 0.46$ , 95% CI = -0.07 to -0.18 s). No significant differences in CON were observed (Table 1). Percentage changes between groups were significantly different from pre- to mid-training (-1% [EXP] vs. 0.4% [CON],  $T = -3.17$ ,  $p = 0.002$ , 95% CI = -2.4 to 0.5%) and from mid- to post-training (-1.9% [EXP] vs. -0.3% [CON],  $T = -3.3$ ,  $p = 0.002$ , 95% CI = -2.5 to -0.6%) for maximal sprint time (Figure 3).

### Relationships between performance variables

In EXP, a statistically significant relationship was observed between  $F_{max}$  and SJ after 4 weeks ( $r = 0.35$ ,  $p = 0.036$ , 95% CI = -0.041 to 0.629%,  $n = 36$ ), as well as after 8 weeks of training ( $r = 0.407$ ,  $p = 0.014$ , 95% CI = 0.141 to 0.622%,  $n = 36$ , Figure 4A). There was also a significant relationship between  $F_{max}$  and 50 m sprint time after 4 weeks ( $r = -0.34$ ,  $p = 0.041$ , 95% CI = -0.592 to -0.075%,  $n = 36$ ), as well as after 8 weeks of training ( $r = -0.40$ ,  $p = 0.015$ , 95% CI = -0.662 to -0.109%,  $n = 36$ , Figure 4B) in EXP. A significant relationship between

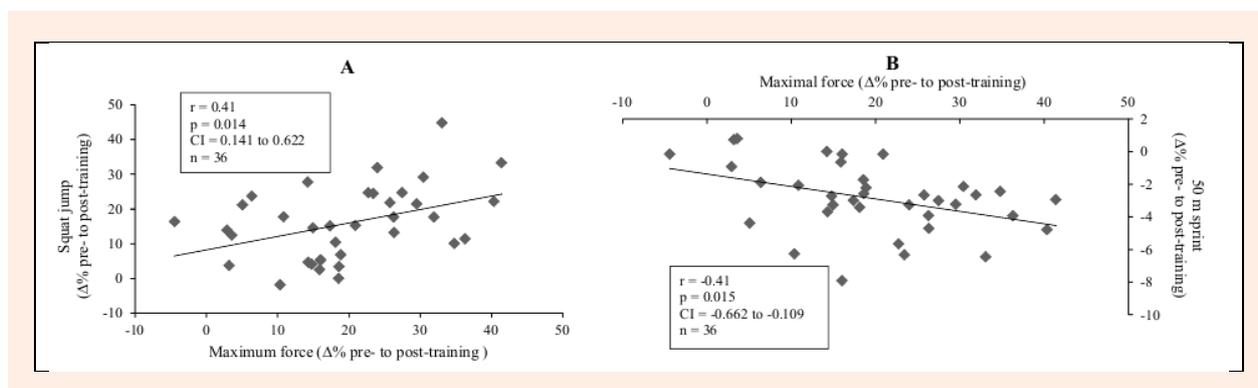
isometric  $F_{max}$  and  $RFD_{100}$  was also observed from pre- to mid-training ( $r = 0.38$ ,  $p = 0.019$ , 95% CI = 0.057 to 0.648%,  $n = 36$ ), as well as from mid- to post-training ( $r = 0.37$ ,  $p = 0.023$ , 95% CI = 0.035 to 0.655%,  $n = 36$ ).

## Discussion

The main findings of this study were that 8 weeks of jump squat training led to simultaneous improvements in all assessed parameters, namely: 1) significant improvements in  $F_{max}$  and  $RFD_{100}$  from pre- to mid-training and mid- to post-training in EXP that were greater than CON, 2) significant improvements in CMJ and SJ from pre- to mid-training in EXP that were greater than CON, 3) significant improvements in 50 m sprint time in EXP at pre- to mid-training and mid- and post-training, which were greater than CON.

Improvements in both CMJ and SJ were evident after the entire power training period in EXP, and these findings were similar to previous studies involving explosive weight/power strength training or in combination with heavy strength training (Lamas et al., 2012; Lyttle et al., 1996; Smilios et al., 2013; Wilson et al., 1993). In the present study, the magnitude of improvements in CMJ was 10 % and in SJ 16 % after pre- to mid-training (4 weeks) and during the next training period no further significant improvements were observed (i.e. improvements plateaued). Interestingly, percentage improvements in CMJ and SJ were 18 % and 15 % from pre- to post-training (10 weeks) in a study by Wilson et al. (1993). Thereafter, a plateau in SJ performance was observed after mid-training (5 weeks) but significant improvements in CMJ continued throughout the jump squat training period, which is in a contrast to our results.

The main difference between the study of Wilson et al. (1993) and the present study is the load used during the jump squats. It may be that use of lighter loads (e.g. 30% 1-RM) have greater efficacy to improve CMJ performance than the medium loads used in the present study (approx. 50-60% 1-RM). Some findings suggest that improvements in loaded jump squat performance are specific to light loads when training is conducted using lighter loads (McBride et al., 2002; Smilios et al., 2013). In contrast, heavy resistance training only has been shown to improve SJ performance over the whole training period



**Figure 4.** Relationship between change in maximum isometric squat force and (A) change in squat jump height, and (B) 50 m sprint time in the experimental group after 8 weeks of training.

(Lamas et al., 2012; Wilson et al., 1993), while in some instances light load jump squat training has not been able to improve SJ performance (e.g. Cormie et al. 2010). Some evidence to support this claim may be indicated by the positive associations in increased Fmax and SJ performance but not between Fmax and CMJ in the present study. Hence, the importance of different neuromuscular qualities on SJ and CMJ performance (Bobbert et al., 1996) may require more targeted training procedures to these specific vertical jumps if continued improvement is desired.

In contrast to vertical jump performance, improvements in isometric maximal force production (Fmax) were significant from pre- to mid-training and also from mid- to post-training. The magnitude of improvements from pre- to mid-training was ~14 % and ~5 % from mid- to post-testing. Short-term jump squat training has been observed to improve maximum strength (either dynamic or isometric testing) (Lamas et al., 2012; McBride et al., 2002; Smilios et al., 2013), however, some studies using light load (0-30% 1-RM) jump squats have not observed improved maximum strength performance (Cormie et al., 2010; Wilson et al., 1993). Furthermore, in studies comparing heavy strength training to jump squat training greater improvements in maximum strength occurred using higher loads (Cormie et al., 2010; Smilios et al., 2013; Wilson et al., 1993). In addition to the positive association between Fmax and SJ improvements, there were also negative associations between Fmax and 50 m sprint time. These findings suggest that improving maximum strength favorably influences some elements of explosive athletic performance. Thus, one possible training strategy for athletes with limited time to improve athletic performance (e.g. team sports) would be to perform jump squats with Pmax loads until a plateau is reached (e.g. approx. 4 weeks and/or 13 sessions) and then use lighter and heavier loads periodically to further increase specific performance. Further research is required to confirm this hypothesis, however.

Previous studies have reported that maximal force production can be increased through muscle activation, as well as increases in cross-sectional area and muscular power following heavy strength training (Kaneko et al., 1983; MacIntosh and Holash, 2000; Shoepe et al., 2003). Following jump squat training, two studies have measured maximum muscle activity using EMG during isometric contraction. There were no changes in VL or VM EMG activity following jump squats with loads of 0-60% 1-RM (Cormie et al., 2010; Lamas et al., 2012). These findings, although limited to 2 studies, would suggest that the improved Fmax in the present study originated from mechanisms other than improved muscle activation. Consequently, morphological or architectural changes within the muscle may have contributed to increases in Fmax. Lamas et al. (2012) observed smaller, but selective increases in type IIa (~15%) and IIx (~19%) fiber cross-sectional area following jump squat compared to heavy strength training. Also, Moss et al. (1997) observed ~3 % ( $p < 0.05$ ) increase in cross-sectional area of the elbow flexors following explosive training. Although Cormie et

al. (2010) did not observe hypertrophy at the whole muscle level (assessed by DXA and ultrasound), the authors observed significantly increase pennation angle that was in-line with the heavy strength training group. These previous findings suggest that perhaps alterations in; muscle size, relative fiber distribution, and/or pennation angle could have contributed to the gain in Fmax in the present study.

The subjects in the present study improved force-time characteristics (i.e. RFD<sub>100</sub>) from pre- to mid-training and also mid- to post-training. Jump squat training with low loads have led to significantly increased EMG rate of rise during CMJ (Cormie et al., 2010) suggesting that neural adaptations are specific to rapid force production. The increased EMG rate of rise observed by Cormie et al. (2010) was accompanied by significant improvements in maximum isometric RFD. It should be noted that interpreting rapid force production and the factors that influence RFD is complex. For example, conflicting data exist regarding the efficacy of explosive power training to induce improvements in RFD with some studies showing no increases (Lamas et al., 2012; Wilson et al., 1993) and others showing improved performance (Häkkinen et al., 1985; Kyröläinen et al., 2005; Winchester et al., 2008). Perhaps one issue is that the test is isometric while the training is performed dynamically, and may lack sensitivity to detect changes due to training (Abernethy and Jürimäe, 1996; Murphy and Wilson, 1996). It may be also that certain exercises are better suited to assess potential improvements in dynamic performance using isometric tests, as Haff et al. (1997) observed strong relationships in the mid-thigh pull exercise ( $r > 0.84$ ). Further complicating this issue is the observed relationship between improvements in Fmax and RFD<sub>100</sub> ( $r = 0.38-0.39$ ,  $p = 0.019-0.023$ ) at pre- to mid-training and mid- to post-training in the present study. Although this relationship may be considered weak to moderate, it indicates that both rapid and maximum force production share some common neuromuscular features. Finally, factors such as different training backgrounds, exercise and test selection, training duration, as well as different assessment of RFD (i.e. force-time, maximum RFD) may have influenced the findings in the literature.

In 50 m sprint time, significant improvements from pre- to mid-training (-1 %,  $p = 0.02$ ), as well as from mid- to post-training (-1.9 %,  $p < 0.001$ ) were observed in the present study. Numerous studies found significant improvements in sprint time after jump squat training over distances ranging from 5 to 40 m, as well as in an agility test (Cormie et al., 2010; Harris et al., 2008; Loturco et al., 2015a; 2015b; McBride et al., 2002; Wilson et al., 1993). To our knowledge no study examined the effect of jump squat training at the distance of 50 m. It is difficult to determine whether these changes are due to improvements in the early (acceleration) or later (maximum speed) phase of running because no split times were measured in the present study. Nevertheless, given the abundance of improved sprint performance over short distances (i.e. 5-30m), the data seem to suggest that the greatest improvements occurred during the acceleration

phase of sprint running. Furthermore, in the study by Sleivert and Taingahue (2004), a relationship between maximal concentric jump power and sprint acceleration was found. This is perhaps logical since longer ground contact time is needed during the acceleration phase of running compared to maximum running speed (Weyand et al., 2000) and therefore, concentric force production of the knee and hip extensors could be the main factors affecting performance (Dorn et al., 2012). The only conflicting data that we are aware of is presented by Cormie et al. (2010), whereby significant improvements were not observed over 10m but after 20m of sprint running. As we observed an association between improved Fmax and 50m sprint performance, it may be that heavier loads are needed to improve maximum force production and sprint acceleration in moderately trained subjects. It could be suggested that future studies focus on different split times and whether improvements are observed following different jump squat loads. With particular reference to team sports, the most optimal loading strategy may be that which targets improvement in neuromuscular features that improve sprint running over 5-30m distances.

One important aspect of the present study was that the external load in our study was individually adjusted according to the power-load curve and instant feedback was provided to the subjects to ensure that all prescribed repetitions were performed with  $\geq 90\%$  of maximum average power output. The inclusion of real-time feedback has been shown to be important to maximize gains during power training compared to training without feedback (Winchester et al., 2009). Real-time feedback has been suggested to provide motivation to subjects to consistently perform/train with maximum effort in each repetition (Harris et al., 2010). Nevertheless, there is a paucity of direct experimental evidence on the efficacy of (knowledge of results) real-time feedback in improving power during a training period. Secondly, individualized loads may be seen as advantageous compared to prescribing loads based on maximum strength (i.e. % of 1-RM), since different neuromuscular characteristics between-athletes may lead to different power-load curves (Izquierdo et al., 2002). Another aspect of the present study, that should be considered when reviewing other literature, is that the power-load curve was determined using maximum average power output not including body weight. Consequently, the loads used during training were at a larger percentage of 1-RM compared to power-load curves determined including body weight in the equation (as shown by Smilios et al., 2013). This higher absolute load used during training may have been better suited to develop a range of athletic performance tasks in the present study.

## Conclusion

Eight weeks of jump squat training resulted in significant improvements in countermovement jump, squat jump, maximum isometric squat force and average force over 100 ms, as well as 50 m sprint time. Only the improvement in vertical jumps plateaued after 4 weeks of training, with further improvements observed from week 4 to 8 in

isometric force and sprint performances. The present study suggests that short-term jump squat training can improve several different athletic performance tasks simultaneously. This may be important, for example, where training duration is limited such as in team sports.

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### Key points

- Jump squat exercise is one of many exercises to develop explosive strength that has been the focus of several researches, while the load used during the training seem to be an important factor that affects training outcomes.
- Experimental group improved performance in all assessed parameters, such as Fmax, RFD<sub>100</sub>, CMJ, SJ and 50 m sprint time. However, improvements in CMJ and SJ were recorded after the entire power training period and thereafter plateau occurred.
- The portable FitroDyne could serve as a valuable device to individualize the load that maximizes mean power output and visual feedback can be provided to athletes during the training.

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