

Research article

## The acute effects of back squats on vertical jump performance in men and women

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### Abstract

The aim of the present study was to investigate the acute effects of performing back squats on subsequent performance during a series of vertical jumps in men and women. Twelve men and 12 women were tested on three separate occasions, the first of which was used to determine their 1-repetition maximum (1-RM) parallel back squat. Following this, subjects performed a potentiation and a control treatment in a counterbalanced order. The potentiation treatment culminated with subjects performing parallel back squats with a load equivalent to 70% 1-RM for three repetitions, following which they performed one counter-movement vertical jump (CMJ) for maximal height every three minutes for a total of 10 jumps. During the control treatment, subjects performed only the CMJs. Jump height (JH) and vertical stiffness (VStiff) were calculated for each jump from the vertical force signal recorded from a force platform. There were no significant changes in JH or VStiff following the treatments and no significant differences in the responses between men and women ( $p > 0.05$ ). Correlations between normalized 1-RM back squat load and the absolute change in JH and VStiff were small to moderate for both men and women, with most correlations being negative. Large variations in response to the back squats were noted in both men and women. The use of resistance exercises performed prior to a series of vertical jumps can result in improvements in performance in certain individuals, although the gains tend to be small and dependent upon the mechanical variable measured. There does not seem to be any differences between men and women in the response to dynamic potentiation protocols.

**Key words:** Back squats, vertical jump, potentiation, vertical stiffness.

### Introduction

Research has shown that performing maximal or near-maximal muscular contractions can produce short-term increases in the maximum force produced by the activated muscles in a phenomenon known as post-activation potentiation (PAP) (Hodgson et al., 2005; Robbins, 2005). The PAP effect has significant implications for strength and conditioning practitioners. For example, the acute effects of PAP can be used to improve performance by including resistance exercises in an athlete's warm-up (Mathews et al., 2003; Smith et al., 2001). Conversely, eliciting the PAP response during resistance training by combining exercises against high loads with those against lighter loads within the same session may confer greater overall gains in explosive strength, and forms the basis of complex resistance training methods (Docherty et al., 2004; Ebben et al., 2000).

Despite the appeal of the PAP effect for strength and conditioning practitioners, the extant research has tended to reveal inconsistent findings. For example, maximal voluntary isometric contractions have been shown to improve subsequent multi-joint explosive movements in some studies (French et al., 2003), yet not others (Robbins and Docherty, 2005). Similarly, heavy back squats have been reported to improve subsequent vertical jump performance (Gourgoulis et al., 2003; Rixon et al., 2007; Young et al., 1998), yet a significant improvement has been absent in other studies (Hanson et al., 2007; Jensen et al., 2003; Jones and Lees, 2003; Mangus et al., 2006; Rixon et al., 2007; Scott and Docherty, 2004). As such, the practical application of PAP methods has recently been questioned by some (Robbins, 2005).

The inconsistencies in the PAP research may arise from a number of sources, with one being the strength of the subjects used in the studies. For example, previous researchers have reported that the PAP effect is greater in subjects who demonstrate greater absolute strength (Gourgoulis et al., 2003; Rixon et al., 2007). However, even when well-trained athletes are used, the results still appear inconclusive (Stone et al., 2008). Another source of inconsistency is the timing of the PAP measurement relative to the potentiating exercise. Comyns et al. (2006) reported that the PAP effect was elicited four minutes after the potentiating exercise, while Jensen and Ebben (2003) speculated that an interval beyond four minutes was required. However, Güllich and Schmidtbleicher (1996) noted considerable individual variation in the response to a PAP protocol, with the effect occurring between 2.5 and 12.5 minutes after the potentiating exercise. The timing of the PAP measurement relative to the potentiating exercise is important given that PAP and fatigue are proposed to exist at opposite ends of a continuum (Rassier, 2000). The loads used during the potentiating exercises have also varied considerably in previous research. For example, improvements in jump performance have been reported after potentiating protocols using loads  $\geq 90\%$  1-repetition maximum (1-RM) (Comyns et al., 2007; Gourgoulis et al., 2003), whereas other researchers have reported improvements in jump performance following squats performed with loads as low as 40 kg (Clark et al., 2006) and even 10% body weight (Burkett et al., 2005). Koch et al. (2003) failed to find a difference in broad jump distance following a warm-up comprised of back squats performed with loads equivalent to 40% or 87.5% 1-RM. Finally, the choice of dependent variable appears to influence the efficacy of PAP protocols. For example, while leg stiffness was increased during a modi-

fied drop jump movement following back squats performed with a load of 93% 1-RM compared to drop jumps performed after squats with 65% and 80% 1-RM, all squat loads resulted in a reduction in flight time (from which jump height can be calculated) during the drop jumps (Comyns et al., 2007).

While there is a wealth of research investigating the PAP effect, few studies have focused on women, although the responses of men and women have been combined in some studies (Chui et al., 2003; Güllich and Schmidtbleicher, 1996; Jensen and Ebben, 2003; Stone et al., 2008). The exceptions are Duthie et al. (2002) and Rixon et al. (2007). Duthie et al. (2002) reported that maximal force averaged across three loaded (30% 1-RM) jump squats was greater in stronger female subjects regardless of whether the jumps were performed prior to three sets of heavy half-squats (the control treatment) or alternated between the sets of heavy half-squats (contrast treatment). When the jump squats were performed following the sets of heavy half-squats (complex treatment) there was no significant difference between the stronger and weaker women. The authors concluded that complex training methods where heavy exercises (3-RM) precede explosive movements may be inappropriate due to reduced performance resulting from the heavy resistance exercises, even in well-trained subjects. Similarly, Rixon et al. (2007) reported that height during vertical jumps was reduced following a series of back squats performed with a load equivalent to 90% 1-RM in a group of women. These results add to the equivocal nature of the extant PAP research. From a practical standpoint, it is important to study the responses of men and women separately so that practitioners may be informed of any potential differences.

If the practical applications of PAP methods for both men and women are to be identified with a view to assisting strength and conditioning practitioners then studies addressing the shortcomings of previous research are required. Therefore, the purpose of the present study was to investigate the acute effects of performing heavy back squats on subsequent performance during a series of vertical jumps in men and women.

## Methods

### Subjects

Twelve men and 12 women volunteered to participate in this study, which was approved by the Institutional Review Board for the Protection of Human Subjects of East Stroudsburg University. The physical characteristics of the subjects are shown in Table 1. All subjects were considered active and reported participating in college sports including football, volleyball, softball and track and field, or participating recreationally in activities including swimming, running and resistance training. All subjects declared that they had been involved in some form of resistance training in the six months prior to the study although the subjects' current use of resistance training protocols was varied, with some subjects using resistance training sessions to develop strength and power utilizing predominantly multi-joint movements, while others were engaged in hypertrophy/strength endurance sessions in-

volving mainly single-joint movements. After being informed of the risks associated with participating in the study the subjects signed informed consent forms prior to the testing. All subjects were asked to refrain from intense exercise and standardize their diet 48 hours prior to the testing sessions.

**Table 1. Physical characteristics of the subjects. Values are means ( $\pm$  standard deviations).**

	Age (years)	Height (m)	Mass (kg)
<b>Men</b>	21.2 (2.6)	1.79 (.09)	85.1 (12.9)
<b>Women</b>	20.9 (1.9)	1.63 (.06)	62.7 (8.1)

### Experimental design

This study investigated the effects of potentiation (back squats) and control treatments on a series vertical jumps in men and women. Each subject performed one jump every three minutes for a total of 10 jumps following each of the two treatments. From a force platform, variables of jump height and vertical stiffness were calculated during each jump. This design allowed for the determination of the effectiveness of back squats as a potentiating exercise in both men and women, given that previous research has reported individual responses in the timing of the potentiation response and few studies have analyzed the response of men and women separately. Similarly, jump height and vertical stiffness comprised the dependent variables as disparate responses in the variables during vertical jumps have been reported in previous research.

All subjects participated in three testing sessions: a 1-RM parallel back squat determination session, a potentiation treatment and a control treatment. All subjects performed the 1-RM determination session prior to any of the other sessions, and the order of the potentiation and control treatments was counterbalanced across the subjects.

### 1-RM parallel back squat

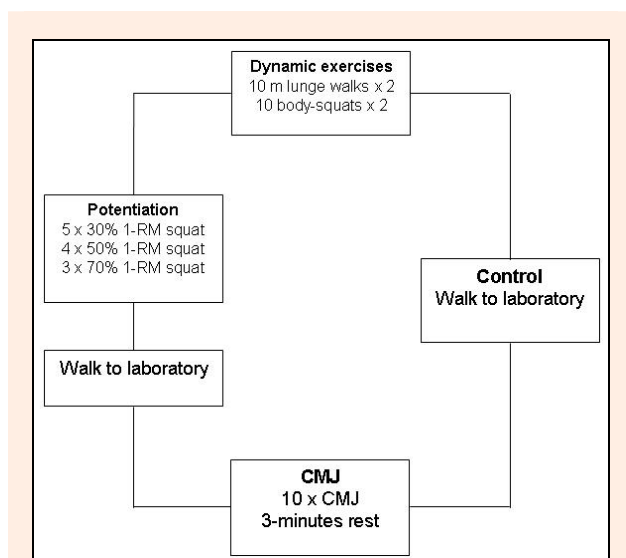
A 1-RM for the parallel back squat was determined for each subject using the protocol outlined by Baechle et al. (2000). A lift was deemed successful if the top of the thighs were parallel to the ground during the lowest point of the descent (determined visually) and the bar continued to move upward throughout the ascent without assistance. Spotters were used during each squat attempt, while a standard 20 kg Olympic barbell and Olympic disks (Ivanko, Reno, NV) were used during the exercise. The maximum load lifted successfully was then normalized to body mass using the equation developed by Jaric (2002). At least three days rest was provided between the 1-RM procedure and the first treatment (potentiation or control).

### Potentiation and control treatments

For the potentiation treatment subjects warmed up by performing a series of dynamic exercises (Figure 1). Following this the subjects performed a series of parallel back squats with varying loads. The subjects first performed five repetitions at 30% of their 1-RM, then four repetitions at 50% 1-RM and finally three repetitions at 70% 1-RM. Two minutes rest was provided between each of the loading sets. The subjects then walked to the laboratory where they performed 10 countermovement verti-

cal jumps (CMJ), with the first CMJ being performed three minutes after completing the final back squat repetition. This protocol is similar to that used in a previous potentiation investigation where significant improvements in sprint running performance were reported (Yetter and Moir, 2008).

For the control treatment the subjects performed the dynamic exercises and then walked to the laboratory to perform the CMJ trials (Figure 1), with the first CMJ being performed three minutes after completing the final body-squat repetition. During all treatment conditions an investigator remained with the subjects to ensure that no other warm up exercises were performed.



**Figure 1.** A schematic representation of the potentiation and control sessions.

### Countermovement vertical jumps

Following the potentiation and control treatments, all subject performed 10 CMJs for maximal height on a force platform (Kistler, type 9286AA, Winterthur, Switzerland) sampling at 1,202 Hz. The subjects were required to perform the jumps with the hands held around the neck to avoid the use of the arms during the movement, and three minutes of passive recovery (quiet sitting) was provided between each jump.

From the vertical force trace during each jump the variables of jump height (JH) and vertical stiffness (VStiff) were calculated following the procedures outlined by Moir et al. (2009). Briefly, JH was calculated from the vertical velocity of the center of mass (COM) at take-off following the integration of the vertical force trace (trapezoid rule), while VStiff was calculated as the ratio of the vertical force to the negative displacement of the COM during the propulsive phase of the jump. The force signal was not filtered prior to the analysis. The coefficients of variation (CV) and intraclass correlation coefficient (ICC) for JH for a single trial in men following this procedure are 2.1% and 0.93, respectively, while for women, the CV and ICC for JH are 2.2% and 0.97, respectively (Moir et al., 2009). The CV and ICC values for VStiff calculated from a single trial are 7.1% and 0.89 for

men, with values of 9.1% and 0.89 for women (Moir et al., 2009).

### Statistical analysis

All statistical analyses were performed using the Statistical Package for the Social Sciences (SPSS for Windows, version 16.0, SPSS Inc., Chicago, IL). Measures of central tendency and spread of the data were represented as means and standard deviations. A repeated-measures ANOVA model was used to assess difference in JH and VStiff as a result of the two treatments. Each model had two within-subject factors (Condition [2-levels] and Jump [10-levels]) and a between-subject factor of gender. A Bonferroni post hoc analysis was performed if any significant differences ( $p \leq 0.05$ ) occurred. Bivariate correlations (Pearson) were used to show the relationship between normalized 1-RM back squat values and absolute differences in the maximum JH and VStiff values recorded following the two treatments for both men and women. The categories of Cohen (1988) were used to establish how meaningful the relationships were, while coefficients of determination (CD), expressed as percentages ( $r^2 \cdot 100$ ), were also computed to identify the variance in the differences that could be explained by normalized strength.

In order to investigate the individual responses to the potentiating treatment the typical errors (TE) for JH and VStiff from the study by Moir et al. (2009) were used. From the TE of a measure the magnitude of a change required for a real effect to have occurred can be calculated, with Hopkins (2000) suggesting that 1.5 – 2.0 times the TE represents a suitable change in a value to identify a real change as a result of an intervention. Therefore, for each subject the values representing 1.5 times the TE were calculated for JH and VStiff for each jump to allow comparison between the potentiating and control treatments. All jumps were included as the timing of the PAP measurement relative to the potentiating exercise has been identified as a source of variation.

### Results

For the men the mean load for the 1-RM parallel back squat was  $158.8 \pm 23.2$  kg, while the women produced a mean 1-RM load of  $79.0 \pm 17.1$  kg. The normalized 1-RM values for the men and women were  $8.07 \pm 1.32$  kg/kg<sup>0.67</sup> and  $5.03 \pm 1.10$  kg/kg<sup>0.67</sup>, respectively.

### Changes in JH and VStiff

Table 2 shows the group means for the maximum JH and VStiff values achieved during the 10 CMJ following the potentiation and control treatments in men and women.

A significant main effect for JH was reported, with the jumps performed following the control treatment being greater than those performed after the potentiating treatment ( $F = 5.187$ ,  $p = 0.03$ ). A significant main effect for jump was also found ( $F = 42.282$ ,  $p < 0.05$ ; JH at 3 minutes > JH at 6 – 30 minutes, JH at 6 minutes > JH at 12 – 30 minutes; JH at 9 minutes > JH at 18 – 30 minutes; JH at 12 minutes > JH at 18 – 27 minutes; JH at 15 minutes > JH at 21 – 27 minutes). A significant jump x

**Table 2.** Values of maximum jump height and maximum vertical stiffness achieved during ten vertical jumps following the potentiation and control treatments. Values are means ( $\pm$  standard deviations).

	Potentiation treatment		Control treatment	
	JH (m)	VStiff ( $\text{kN}\cdot\text{m}^{-1}$ )	JH (m)	VStiff ( $\text{kN}\cdot\text{m}^{-1}$ )
<b>Men</b>	.38 (.06)	4.74 (.86)	.38 (.06)	4.82 (.73)
<b>Women</b>	.26 (.06)	3.73 (.94)	.26 (.06)	3.64 (.67)

JH = jump height; VStiff = vertical stiffness.

gender interaction was found ( $F = 21.184$ ,  $p = 0.000$ ) with the men demonstrating a significantly greater reduction in JH from those jumps performed at three and 24 minutes ( $F = 8.282$ ,  $p = 0.01$ ) and between those performed at three and 27 minutes ( $F = 5.741$ ,  $p = 0.03$ ) compared to the women. Finally, a significant main effect for gender was also reported with men producing greater JH compared to the women ( $F = 21.184$ ,  $p < 0.05$ ). For VStiff values, only a significant main effect for gender was found ( $F = 17.432$ ,  $p < 0.05$ ), with the men producing greater stiffness values compared to the women.

### Relationships between strength and changes in JH and VStiff

For the men, a large negative relationship was found between the absolute change in the maximum JH and the normalized 1-RM load ( $r = -0.54$ ;  $CD = 29\%$ ), while a small positive relationship was found for women ( $r = 0.10$ ;  $CD = 1\%$ ). Moderate negative relationships were reported between the absolute change in the maximum VStiff value and normalized 1-RM load in men ( $r = -0.43$ ;  $CD = 18\%$ ) and women ( $r = -0.36$ ;  $CD = 13\%$ ).

### Individual responses to the potentiation treatment

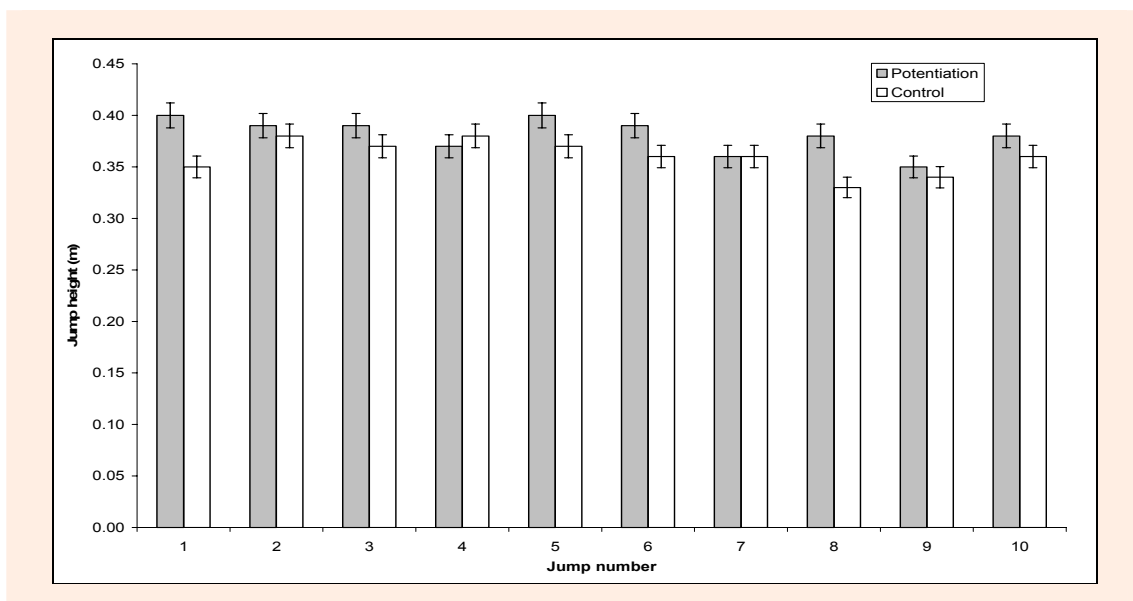
Five men produced their greatest JH value following the PAP treatment, with four women responding similarly. For VStiff values, five men and six women produced their greatest values following the potentiation treatment. Figures 2 and 3 show the height of the 10 jumps for two men following the potentiation and control treatments. The error bars represent 1.5 times the TE of the measure. Subject MR (Figure 2) showed improvements in maxi-

mum JH following the potentiation treatment in comparison to the control treatment (Jumps 1, 5, 6 and 8), while subject LH (Figure 3) showed a reduction in JH across all 10 jumps. In terms of normalized strength, these two subjects were ranked seventh (MR) and second (LH) in the present study.

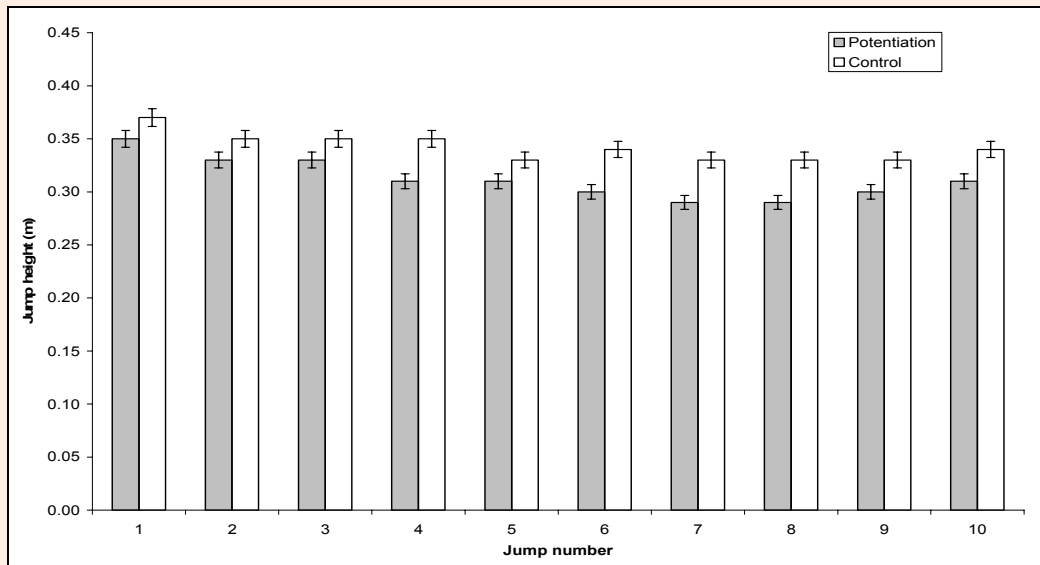
Figures 4 and 5 show the height of the 10 jumps for two women following both treatments. Subject TT (Figure 4) showed improvements in maximum JH following the potentiation treatment in comparison to the control treatment (Jumps 2 and 7). Subject LH (Figure 5) showed a large reduction in JH across the first three jumps following potentiation compared to the control treatment, and yet improved during jump eight. These two subjects were ranked the fourth (TT) and fifth (LH) strongest women in the present study.

### Discussion

The purpose of the present study was to investigate the acute effects of performing back squats on subsequent performance during a series of vertical jumps in men and women. Previous researchers have reported no change in JH following heavy back squats performed by men (Mangus et al., 2006; Scott and Docherty, 2004). However, these studies failed to account for individual differences in the timing of the PAP response following the potentiating exercise. In the present study, JH was assessed over a 30 minute period in order to account for such individual responses. Despite this design, a significant increase in JH following the potentiation treatment for both men and women was absent. Indeed, when JH was collapsed across



**Figure 2.** Jump height recorded across 10 jumps separated by three minutes following the potentiation and control treatments in male subject MR. Error bars are 1.5 times the typical error of the measure.

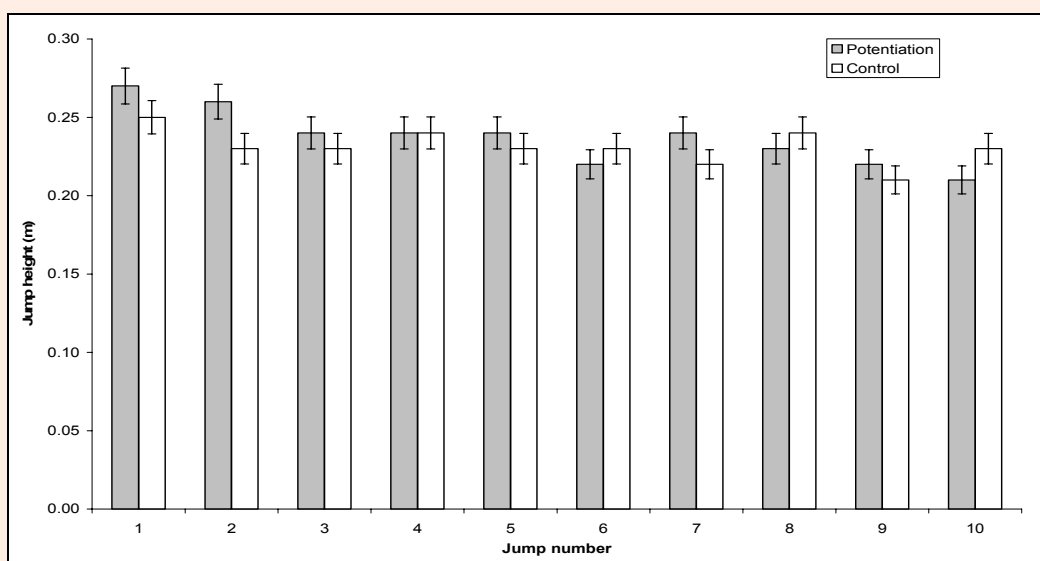


**Figure 3.** Jump height recorded across 10 jumps separated by three minutes following the potentiation and control treatments in male subject JH. Error bars are 1.5 times the typical error of the measure.

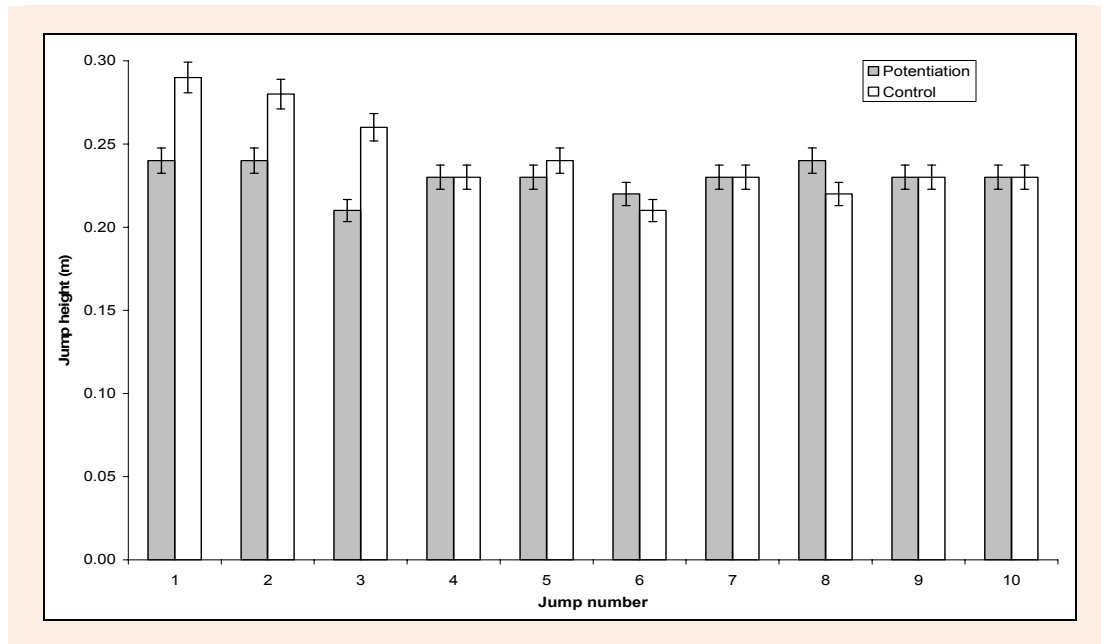
all 10 jumps it was actually found that the potentiation treatment resulted in lower jump heights, with no difference in the response between the genders. Two previous studies have investigated the effects of heavy back squats on vertical jump performance in women, with a reduction in JH being reported in both (Duthie et al., 2002; Rixon et al., 2007). When investigating the PAP response in a group of well-trained men, Comyns et al. (2007) reported that flight time during a modified drop-jump was significantly reduced.

In the present study, VStiff values were unchanged following the potentiation treatment in both men and women. The calculation of VStiff in the present study represents the ratio of eccentric force generation to the negative displacement of the COM during propulsion. It is possible that the resistance exercise performed in the

present study was insufficient stimulus to enhance the eccentric force capabilities of the active musculature. Babault et al. (2008) recently reported that isometric contractions induced greater PAP in subsequent shortening compared to lengthening contractions, possibly due to changes in myofilament arrangement,  $Ca^{2+}$  sensitivity or muscle stiffness differences. Again however, it should be noted that in the present study VStiff was not significantly reduced as a result of performing back squats prior to the jumps when the subjects were grouped. While changes in myofilament arrangement and/or  $Ca^{2+}$  sensitivity remain plausible explanations for the lack of observed PAP in the present study, it would also seem possible that changes in the amortization phase of the stretch-shortening cycle (SSC) during the VJ trials could provide a viable explanation. It has been suggested that increased time spent in the



**Figure 4.** Jump height recorded across 10 jumps separated by three minutes following the potentiation and control treatments in female subject TT. Error bars are 1.5 times the typical error of the measure.



**Figure 5.** Jump height recorded across 10 jumps separated by three minutes following the potentiation and control treatments in female subject LH. Error bars are 1.5 times the typical error of the measure.

amortization phase results in the loss of stored elastic energy in the form of heat (Komi and Bosco, 1978), and would seem a likely contributor in light of the lack of change in VStiff. If one considers that PAP and fatigue are purported to lie on opposite ends of the same spectrum, it appears feasible that some subjects may have experienced fatigue during the protocol which may have manifested itself as an elongation of the amortization phase during the VJ trials. In this case, subsequent concentric force production would have been decreased and PAP ameliorated. Certainly this explanation remains speculative as the time spent in the phases of the SSC was not able to be measured in the present study.

The lack of significant improvements following the resistance exercise in the present study may be due to a lack of specificity between the back squat and vertical jump movement. For example, previous researchers have noted that PAP protocols are muscle length dependent (Moore et al., 1990; Rassier et al., 1997). Future researchers should investigate the differences following resistance exercises that mimic the joint ranges of motion produced during the vertical jump performance. It is also worth noting that previous researchers that have reported improvements following resistance exercise protocols have used heavier loads than those used in the present study (e.g. Chiu et al., 2003; Gourgoulis et al., 2003; Rixon et al. 2007), which could account for the present findings. However, the protocol used in the present study has been shown previously to improve sprint running performance in resistance-trained men (Yetter and Moir, 2008). Similarly, even loads as light as 40 kg (Clark et al. 2006) and 10% of the athlete's body weight has been shown to improve subsequent JH (Burkett et al., 2005), while Koch et al. (2003) failed to show a difference in broad jump distance following back squats performed with 40% or 87.5% 1-RM. The lack of significant improvement observed in the present study may have been caused by the heterogeneity of the subjects in terms of their muscular

strength given the proposed mediating role that strength plays in the PAP response.

#### **Relationships between strength and changes in JH and VStiff**

Previous researchers have reported that the PAP effect is greater in stronger subjects when strength is assessed in absolute terms (Gourgoulis et al., 2003; Rixon et al. 2007). For the men in the present study, a large negative relationship was found between normalized maximum strength and the difference in maximum JH between the two treatments, while a moderate negative relationship was reported between absolute change in VStiff and normalized 1-RM. For the women in the present study, a small positive relationship between normalized maximal strength and the difference in maximum JH was found, although a moderate negative relationship was reported when VStiff was assessed. It should be noted that these relationships still leave over 70% of the variance in the change in JH and VStiff during CMJ performance unexplained. Interestingly, Duthie et al. (2002) reported that heavy back squats performed prior to vertical jumps resulted in reduced performance in women, even when absolute strength values were considered. Unfortunately, none of the previous studies that have assessed absolute measures of strength have reported correlation coefficients, making direct comparisons with the findings of the present study difficult. When using normalized values, Mangus et al. (2006) reported small negative correlations between maximal strength and the change in jump height following both quarter- and half- squats performed with 90% 1-RM in men. Therefore, given the present findings and those of Mangus et al. (2006), it appears that normalized strength values do not aid the practitioner in identifying those subjects that may respond to a PAP protocol. It should be noted that even when absolute strength was considered in the present study, the strength of the relationships was not changed substantially (with the excep-

tion of VStiff in men where  $r = -0.17$ ). Future research that attempts to establish well-defined minimum absolute strength criteria for elicitation of PAP appears to be warranted, and would be beneficial for practitioners attempting to apply this information in their training programs.

### Individual responses to the potentiation treatment

Mangus et al. (2006) reported that the use of heavy squats prior to CMJ performance should be individualized for men, with only half of the subjects in their study actually demonstrating an improvement in CMJ performance. A comparison of the maximum JH values achieved following the potentiation and control treatments in the present study revealed that five men actually improved as a result of the squats, with one subject showing no change. Although similar findings were noted for VStiff, the subjects tended to be different. For the women, four subjects increased maximum JH following the potentiation treatment, with a further four demonstrating no change. Half of the women increased VStiff following the heavy resistance exercise, but as with the men, these subjects did not necessarily demonstrate concomitant improvements in JH. Previous investigators have noted that the use of prior resistance exercise does not interfere with jumping performance, despite no obvious improvements (Jones and Lees, 2003). However, the present results demonstrate that back squats can interfere with jump performance in some subjects, including those that can be considered strong within the context of the present sample. Comyns et al. (2007) recently reported that leg stiffness was increased during a modified drop jump movement following back squats performed with a load of 93% 1-RM, while no differences were found in leg stiffness following squats with 65% and 80% 1-RM. Interestingly, all squat loads resulted in a reduction in flight time (from which JH can be calculated) during the drop jumps. It is therefore important to consider the dependent variable in studies investigating the effects of resistance exercises on jump performance, particularly given the disparate responses in JH and VStiff reported for individual subjects in the present study.

### Conclusion

The use of heavy resistance exercises performed prior to a series of vertical jumps can result in improvements in performance in certain subjects, although the gains tend to be small. There does not seem to be any differences between men and women in the response to PAP protocols. As such, if strength and conditioning practitioners wish to use complex training methods, an attempt should be made to individualize the protocols used in terms of time between the PAP response and the potentiating exercises. Practitioners should demonstrate caution as subsequent vertical jump performance in certain subjects can actually be hindered by the use of prior back squats. Similarly, consideration should be given to the mechanical variable that is selected to demonstrate an improvement following such protocols given the likely disparate responses in individual subjects.

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## Key points

- Substantial individual responses were noted in both men and women in response to the PAP protocol used in the present study.
- The choice of dependent variable influences the efficacy of the PAP protocol, with JH and VStiff demonstrating disparate responses in individual subjects.
- Such individual responses may render such PAP protocols impractical for strength and conditioning practitioners as the protocols are likely to require individualizing to each athlete.