TITLE PAGE

Title:

Effect of back squat depth on lower body post-activation potentiation

Running head:

Effects of squat on PAP

Laboratory:

Sport and Exercise Physiology, Cardiff Metropolitan University, Cardiff, UK

Authors:

Joseph I. Esformes[1] and Theodoros M. Bampouras[2]

Department:

[1] Cardiff School of Sport

[2] Faculty of Health and Wellbeing, Sport and Physical Activity

Institution:

[1] Cardiff Metropolitan University, Cardiff, UK

[2] University of Cumbria, Lancaster, UK

Corresponding author:

Dr. Joseph I. Esformes, PhD, CSCS, Cardiff Metropolitan University, Cardiff School of Sport, Cyncoed Road, Cardiff, CF23 6XD, UK / Tel. no.: +44 (0) 29 2041 7060 / Fax no.: +44 (0) 29 2041 6768/ E-mail: jesformes@cardiffmet.ac.uk

BLINDED TITLE-ONLY PAGE

Title:

Effect of back squat depth on lower body post-activation potentiation

ABSTRACT

Postactivation potentiation (PAP) refers to increased muscular force generation following previous muscular activity. Various studies have used different squat variations as a PAP stimulus; however, different squat depths can have different mechanical and physiological demands that could yield different PAP levels and subsequent performance. The study aimed to compare the effects of the parallel (PS) and quarter (QS) squat on PAP. Twenty seven semi-professional male rugby union players (mean±SD, 18±2 years, 87.2±5.4 kg, 180.7±5.1 cm) performed a countermovement jump (BL-CMJ) followed by a 10-min rest. Subsequently, they performed 3 PS or QS, at each squat's respective 3 repetition maximum load, in a randomised, counterbalanced order. Following a 5-min rest, another CMJ was performed (POST-CMJ). CMJ jump height (JH), peak power (PP), impulse (I), and flight time (FT) were recorded using a contact mat. BL-CMJ and POST-CMJ pairwise comparisons for all variables were conducted for each squat type to examine performance changes. Delta values were compared to examine whether one squat produced better CMJ results. Both squats induced PAP for all the variables ($P<0.05$), while PS produced better results than QS ($P<0.05$; JH, 4.6±2 v 3.5±2 cm; I, 15±6 v 12±5 N·s; PP, 285±109 v 215±96 W; FT, 34±23 v 26±11 ms for PS v QS). This is the first study to demonstrate that different squat types can induce PAP and that PS is more beneficial for subsequent CMJ performance compared to QS. It is suggested that the deeper depth of PS, which increases gluteus maximum activation and work produced, is responsible for the increased CMJ performance.

Keywords: complex training, power performance, lower body exercise

INTRODUCTION

Increased muscular activity can result in decreased neuromuscular force generation (19). However, it can also enhance subsequent force generation and improve strength and power performance (3,8,11,16,21,23), a phenomenon termed post-activation potentiation (PAP). PAP has been attributed to three possible mechanisms; regulatory light chains phosphorylation, increased recruitment of motor units, and muscle fibre pennation angle change (for review see 22). In the first mechanism, Ca^{2+} release from the sarcoplasmic reticulum increases, and so does the sensitivity of the actin-myosin interaction, which alters the structure of the myosin head and results in a higher force-generation state of the cross-bridges (19). For the second mechanism, motor unit recruitment can be increased by increased excitation potential due to previous muscular contractions. This excitation, which can last for several minutes, results in enhanced force generation (12). Finally, previous muscular contractions will reduce the muscle fibre pennation angle, allowing more faithful force transition in subsequent contractions (14).

Numerous studies have used the back squat as a stimulus to induce PAP and assess its effects on strength and power performance (3,8,16,21,23), due to its wide use by practitioners and researchers. However, different variations of the exercise have been used depending on the depth of the squat. For example, Esformes et al (8) compared half squats to plyometric exercises as a stimulus for inducing PAP. Kilduff et al (16) used full squats to examine optimal recovery time following the stimulus. Furthermore, Smilios et al (21) used both half and jump squats to examine the effect of load on PAP. Finally, Witmer et al (23) used parallel squats to examine their effect on subsequent jump performance.

The use of strength-power potentiating complex pairs for enhancing power performance often entails the use of a heavy load squat exercise followed by a jumping, ballistic activity (e.g. 8,15). However, in addition to the load (11,21), the variation in the depth to which the squat is performed can affect the performance outcome (17). For example, Caterisano et al (1) reported higher gluteus maximum activation with increasing squat depth. However, this muscle also plays an important role in CMJ performance (10). Therefore, the various squats that have been used in research and are used in practice to allow for higher sport-specificity and loading patterns could have an effect on subsequent jumping performance. It is plausible that higher activation of this muscle could induce higher PAP, resulting in better power performance during subsequent jumping performance. In addition, the deeper squat would also require more work to be performed, potentially resulting in greater muscle excitation. Therefore, the aim of the current study was to compare the effect of prior execution of parallel or quarter squats on subsequent countermovement jumping performance variables.

METHODS

Experimental Approach to the Problem

The aim of the present study was to compare the effect of parallel or quarter squats (routinely used in training practice) as a PAP stimulus on subsequent countermovement jumping performance. Twenty seven semi-professional male rugby union players performed a countermovement jump (CMJ) followed by a 10-min rest. Subsequently, they performed 3 repetitions of a parallel or quarter squat at each squat’s respective three repetition maximum (3RM) load. Subjects then rested for 5 min and performed another CMJ. To avoid any order bias, a counterbalanced, randomised order design was employed. Pairwise comparisons between before and after conditioning stimulus were carried out on all performance variables (jump height, impulse, peak power, and flight time) as well as the delta values , to provide an indication of any PAP effects.

Subjects

Twenty seven semi-professional male rugby union players (mean ± SD, age, 18 ± 2 yrs; body mass, 87.2 ± 5.4 kg; height, 180.7 ± 5.1 cm) agreed to participate in the study. The subjects were in the competition phase of their annual training cycle. Their sport training programme included a minimum of three sessions of resistance training per week, with training loads ranging from 40% - 90% of 1RM. All subjects had experience of resistance training prior to the study and were free from any upper body injuries at the time of the study for at least one year. Subjects were asked to refrain from eating 2 h before examination and from drinking coffee and alcohol 24 h prior to each visit to the laboratory. Subjects were allowed to consume water ad libitum prior to and during the exercise task. Approval from Cardiff Metropolitan University's Ethics Committee was granted and written informed consent was obtained from all subjects.

Procedures

Subjects initially visited the laboratory to be familiarized with the experimental protocol and the subjects' weight and height were measured. Height was measured to the nearest 0.1 cm using a stadiometer (Harpenden, UK) and weight was measured to the nearest 0.1 kg using a calibrated balance beam scale (Seca, UK). Subsequently, each subject's 3RM for the parallel squat (PS) and the quarter squat (QS) were determined according to the guidelines set by the National Strength and Conditioning Association (13). 3RM was defined as the load that caused failure on the third repetition but without loss of proper exercise technique. To establish the 3RM load, subjects attempted 3 repetitions of a load and, if successful, increased the loading. A 5-min rest interval was allowed between trials, with 3 to 5 trials typically required for determining each subject's 3RM. Parallel squat was deemed to be successful if the subject could descend until the inguinal fold was lower than the patella (60^o – 70^o knee joint angle; full extension = 180^o), while QS when the subjects' knees flexed to ~135^o knee joint angle. Subjects had to rise without help for both squat types.

Following the first visit, subjects returned to the laboratory on two separate occasions for the experimental sessions. At the start of each experimental session, the subjects were required to complete a standardised warm-up of 5 min of light-intensity cycling and a number of dynamic stretches specific to muscles involved in the relevant exercises. A 5-min rest interval was allowed after the end of the warm-up.

The subjects performed a countermovement jump that served as baseline (BL-CMJ). Subjects kept their arms on their waist during the jump to isolate the leg contribution and the depth was self-selected. After the CMJ, a 10-min rest was allowed, followed by one of the conditioning contractions. The conditioning contractions were one set of three repetitions of either PS or QS at 3RM. Each conditioning contraction was applied in a counterbalanced, randomised order on separate days. All exercises were executed using a squat rack, an Olympic weightlifting bar, and free weight plates. Experienced spotters were present at all times to ensure safety of subjects and appropriate exercise technique execution. In addition, the spotters visually inspected and confirmed the depth of the squat and provided verbal feedback when needed. Finally, following a 5-min rest, the subjects performed another CMJ (POST-CMJ). CMJ performance variables assessed were jump height (JH), impulse (I), peak power (PP), and flight time (FT) using a jump mat (Smartjump, Fusion Sport, Brisbane, Australia).

Testing took place on the same time of day for each subject, and with a minimum of 24 hours intervening between testing sessions. Subjects refrained from any strenuous activities or resistance/ plyometric training at least 48 hours before each testing session.

Statistical analyses

Normality of all raw data and delta values was examined and confirmed using the Kolmogorov-Smirnov test. Pairwise comparisons were made between pre- and post-squat CMJ values for all variables for each squat type. Further, pairwise comparisons between squats were made for the BL-post delta values for all variables. Finally, effect sizes (ES; 4) were calculated for all comparisons. All data are presented as mean ± SD, unless otherwise stated. Significance was set at $P \leq 0.05$ and all statistical analyses were conducted using SPSS v19.0.

RESULTS

Subjects' 3RM load for PS and QS were 183.3 ± 17.3 kg and 200.7 ± 17.3 kg, respectively. All POST-CMJ variables improved significantly compared to BL-CMJ for both PS and QS ($P < 0.05$; Table 1). In addition, delta values for PS were significantly higher than QS for all variables examined ($P < 0.05$; Table 1).

INSERT TABLE 1 HERE

ES ranged from 0.53 – 1.23 for the BL- to POST-CMJ comparisons (Table 2), indicating moderate to large effects (4). For the delta values, the effect was moderate as ES ranged from 0.38 – 0.67 (Table 2).

INSERT TABLE 2 HERE

DISCUSSION

The aim of the present study was to examine if subsequent CMJ performance could be enhanced by variations of the back squat as a prior conditioning stimulus and whether a particular squat depth produced higher benefits. Our results show that both QS and PS increase CMJ performance variables and that PS achieves increased performance compared to QS.

The squat exercise has received substantial attention in the literature, either as the subject of research (e.g. 6,7,9), or as the intervention used to induce PAP (e.g. 3,8,16,21,23), due to its widespread use in the field and benefits it can offer to training (2,24). However, the high mechanical demands it poses to the body and subsequent likelihood of injury (2,9) as well as the specific flexibility requirements to allow for correct execution (18) has lead to practitioners using different variations of the back squat exercise, primarily by limiting the range of movement (2,6,24). This decreased range of motion allows the athlete to lift a higher load compared to full of parallel squatting, due to the higher mechanical advantage in the knee joint, and as a result overload the musculature. Indeed, analysis of our results showed that the QS 3RM was 9.5% ($P < 0.001$) higher than the PS 3RM load.

On the other hand, parallel squats have been shown to be more effective in engaging the gluteus maximus muscle (1), an important muscle in all hip extension movements (10). Training using reduced range of motion can reduce joint mobility (20), whilst the heavier load allowed by the QS presents a larger risk of back injury and the possibility of changing the power characteristics of the muscle (24).

It has previously been suggested that PAP affects primarily the rate of force development (RFD; 22). The current findings appear to support this notion. Although in the present study, the depth of the downward phase of the CMJ was self selected, and we are therefore unable to know whether the same depth was used for both PRE- and POST-SQUAT CMJ, it is unlikely that the subjects' would have changed the depth they utilised between the two jumps. Based on this hypothesis, the increased JH and FT are a result of the increased I, which is the main predictor of JH (17) and, consequently, of FT. The increase in I must have been produced by the muscles' ability to generate higher force over the same period of time, suggesting an improvement in RFD following the conditioning contraction. Finally, the concurrent increase in power also points towards an increased RFD.

The increased CMJ performance following PS compared to QS found in our study can be attributed to the difference in range of movement between the two squat types and the impact it has on work produced by the gluteus maximus and the rest of the relevant muscles. The deeper squat position in PS increases the hip joint angle (5), resulting in a more stretched gluteus maximus, an important muscle in hip extension (10). This stretch increases the work required to produce the necessary torque to extend the hip. Further, the mechanical disadvantage of the knee joint during the amortisation phase of the PS dictates that more force is required to overcome inertia, further increasing the work performed. The additional work would require higher recruitment of motor units, therefore increasing the excitation potential of the muscle and augmenting its performance during the CMJ.

PRACTICAL APPLICATIONS

Both QS and PS are widely used in the training setting. Notwithstanding the reasons for selection of one over the other, the present study demonstrated that both squat types can provide sufficient stimulus to induce PAP. However, the PS produced superior power performance compared to QS. Therefore, practitioners can use the parallel squat as a PAP conditioning contraction stimulus for acutely enhancing subsequent power performance, while allowing greater range of motion in the hips, knees and ankles with less compressive loads in the lower back.

ACKNOWLEDGEMENTS

The authors would like to thank Ms. Annicka Jones for her help with data collection.

REFERENCES

1. Caterisano, A, Moss, R, Pellinger, T, Woodruff, K, Lewis, V, Booth, W, and Khadra, T. The effect of back squat depth on the EMG activity of 4 superficial hip and thigh muscles. *J Strength Cond Res* 16: 428–432, 2002.
2. Chandler, TJ and Stone, MH. N.S.C.A. position paper: The squat exercise in athletic conditioning: A position statement and review of the literature. *Nat Strength Cond Assoc J* 13: 51–58, 1991.
3. Chiu, LZ, Fry, AC, Weiss, LW, Schilling, BK, Brown, LE, and Smith, SL. Postactivation potentiation response in athletic and recreationally trained individuals. *J Strength Cond Res* 17: 671-677, 2003.
4. Cohen, J. Statistical power analysis for the behavioral sciences. 2nd ed. London, UK: Routledge, 1988.
5. Domires, ZJ, and Challis, JH. The influence of squat depth on maximal vertical jump performance. *J Sports Sci* 25: 193-200, 2007.
6. Drinkwater, EJ, Moore, NR, and Bird, SP. Effects of changing from full range of motion to partial range of motion on squat kinetics. *J Strength Cond Res* 26: 890–896, 2012.
7. Dugan, EL, Doyle, TL, Humphries, B, Hasson, CJ, and Newton, RU. Determining the optimal load for jump squats: a review of methods and calculations. *J Strength Cond Res* 18: 668-674, 2004.
8. Esformes, JI, Cameron, N, and Bampouras, TM. Post-activation potentiation following different modes of exercise. *J Strength Cond* Res 24: 1911-1916, 2010.
9. Fry, AC, Smith, JC, and Schilling, BK. Effect of knee position on hip and knee torques during the barbell squat. *J Strength Cond Res* 17: 629-633, 2003.

10. Fukashiro, S, and Komi, PV. Joint moment and mechanical power flow of the lower limb during vertical jump. *Int J Sports Med* Suppl 1: 15-21, 1987.

11. Gourgoulis, V, Aggeloussis, N, Kasimatis, P, Mavromatis, G, and Garas, A. Effect of a submaximal parallel-squats warm-up program on vertical jumping ability. *J. Strength Cond Res* 17: 342-344, 2003.

12. Güllich, A, and Schmidtbleicher, D. MVC induced short-term potentiation of explosive force. *New Studies in Athletics* 11: 67-81, 1996.

13. Harman, E, and Pandorf, C. Principles of Test Selection and Administration. In: Essentials of Strength Training and Conditioning. Baechle, TR and Earle, RW, eds. Champaign, IL: Human Kinetics, 2000.

14. Hatfield, FC. Power: A Scientific approach. Chicago, IL: Contemporary Books, 1989.

15. Jones, P, and Lees, A. A biomechanical analysis of the acute effects of complex training using lower limb exercises. *J Strength Cond Res* 17: 694-700, 2003.

16. Kilduff, LP, Bevan, HR, Kingsley, MI, Owen, NJ, Bennett, MA, Bunce, PJ, Hore, AM, Maw, JR, and Cunningham, DJ. Postactivation potentiation in professional rugby players: optimal recovery. *J. Strength Cond Res* 21: 1134-1138, 2007.

17. McBride, JM, Kirby, TJ, Haines, TL, and Skinner, J. Relationship between relative net vertical impulse and jump height in jump squats performed to various squat depths and with various loads. *Int J Sports Physiol Perform* 5: 484-496, 2010.

18. Osar, E. Corrective exercise solutions to common hip and shoulder dysfunction. Chichester, England: Lotus Publishing, 2012.

19. Rassier, DE, and Macintosh, BR. Coexistence of potentiation and fatigue in skeletal muscle. *Braz J Med Biol Res* 33: 499-508, 2000.

20. Sahrmann, SA. Diagnosis and treatment of movement impairment syndromes. London: Mosby, 2002.

21. Smilios, I, Pilianidis, T, Sotiropoulos, K, Antonakis, M, and Tokmakidis, SP. Short-term effects of selected exercise and load in contrast training on vertical jump performance. *J. Strength Cond Res* 19: 135-139, 2005.

22. Tillin, NA, Bishop, D. Factors modulating post-activation potentiation and its effect on performance of subsequent explosive activities. *Sports Med* 39: 147-166, 2009.

23. Witmer, CA, Davis, SE, and Moir GL. The acute effects of back squats on vertical jump performance in men and women. *J Sports Sci Med* 9: 206-213, 2010.

24. Yule, S. Exercise of the month: the back squat. *Professional Strength & Conditioning*, 1: 11-15, 2005.

TABLES

Table 1. Performance variables scores (mean±SD) for countermovement jump (CMJ) before (BL-CMJ) and after (POST-CMJ) the quarter (QS) and parallel (PS) squat conditioning contraction stimuli and Δ values (difference POST-CMJ – BL-CMJ).

	QS			PS		
Variables	BL-CMJ	POST-CMJ	Δ	BL-CMJ	POST-CMJ	Δ
Jump Height (cm)	36±4	40±4*	3.5±2	36±4	41±4*	4.6±2†
Impulse (N•s)	247±22	259±23*	12±5	247±24	262±24*	15±6†
Peak power (W)	4367±393	4582±397*	215±96	4367±427	4652±405*	285±109†
Flight time (ms)	545±32	571±32*	26±11	545±33	579±31*	34±13†

*, significantly different to BL-CMJ ($P \leq 0.05$); †, significantly different to QS Δ values ($P \leq 0.05$).

Table 2. Effect sizes (ES) for countermovement jump (CMJ) before (BL-CMJ) and after (POST-CMJ) the quarter (QS) and parallel (PS) squats conditioning contraction stimuli and Δ values (difference POST-CMJ – BL-CMJ).

	QS	PS	
Variables	BL-POST	BL-POST	Δ
Jump Height (cm)	ES = 0.99	ES = 1.23	ES = 0.54
Impulse (N•s)	ES = 0.53	ES = 0.62	ES = 0.54
Peak power (W)	ES = 0.54	ES = 0.67	ES = 0.67
Flight time (ms)	ES = 0.8	ES = 1.05	ES = 0.38