The effect of heavy resistance exercise on repeated sprint performance in youth athletes.

Abstract

This investigation assessed whether using prior heavy resistance exercise would improve the repeated sprint performance of 16 trained youth apprentice soccer players (Age 17.05 ± 0.65 years; height 182.6 ± 8.9 cm; body mass 77.8 ± 8.2 kg). In the first session individual 1 repetition max was measured. In sessions 2 and 3, participants performed a running-based repeated anaerobic sprint test with and without prior heavy resistance exercise of 91% 1 repetition max utilising a squat movement. Times were recorded for each of the 6 sprints performed in the repeated anaerobic sprint test and summed to provide total time. T-tests were used to compare times for the two exercise conditions for corresponding sprint within each repeated anaerobic sprint test as well as the total time. Analysis revealed significantly reduced total time with use of heavy resistance exercise (33.48 (± 1.27) vs. 33.59 (± 1.27); $p = 0.01$). Sprints 1 ($p = 0.05$) and 2 ($p = 0.02$) were also faster in heavy resistance exercise condition (5.09 (± 0.16) vs. 5.11 (± 0.16) and 5.36 (± 0.24) vs. 5.45 (± 0.26) seconds respectively) although no other differences were shown. Findings demonstrate improved sprint times of trained adolescent soccer players after heavy resistance exercise although this benefit appears not as sustained as in adult participants.

Key Words

repeated anaerobic sprint test, post-activation potentiation, sprint performance.

Word count: 2805

1. Introduction

At the start of the sprint action, a performer produces powerful extensions of the hip, knee and ankle joints to accelerate their body mass (Delecluse, 1997). Strategies to maximise sprint performance are viewed as essential by both coaches and athletes (Bishop & Claudius, 2005; Onkuno et al., 2013). One way in which sprint performance can be improved is through the generation of greater muscular power, leading to improved peak acceleration and increased maximal force output, muscle twitch force, H-reflex amplitude and rate of force development (Chiu et al., 2003; Hilficker, Klaus, Lorenz, & Marti**,** 2007; Hodgson, Docherty, & Robbins, 2005; Sale, 2002; Xenofondos et al., 2010).

Acute enhancement of muscular power has been shown to occur following a bout of heavy resistance exercise. This exercise elicits post-activation potentiation which increases force and power production in excess of what can be achieved without the use of heavy resistance exercise (Bevan et al., 2010; Khamoui et al., 2009; Needham, Morse, & Degens, 2009; Robins, 2005; Till & Cooke, 2009; Weber, Brown, Coburn, & Zinder, 2008; Yetter & Moir, 2008). When utilising this potentiation, time taken to complete a 30m sprint has been shown to decrease (Bevan et al., 2010; Chatzopoulos et al., 2007; Linder et al., 2010). Heavy resistance exercise has also been shown to be effective for adult handball players during repeated sprint tests, suggesting its applicability to team sports (Okuno et al., 2013). The ability to attain these physiological benefits are however, thought to relate to the condition of the participants (Berning et al., 2010; Gourgoulis, Aggeloussis, Kasimatis, Mavromatis, & Garas, 2003; Okuno et al. 2013) and level of musculature tissue development (Ausubel, 2002). These characteristics can be directly influenced by the age of the participant as children possess less voluntary muscle speed, strength and power, even when corrected for age or maturation state (Van Praagh & Dore, 2002). Likewise, children and adolescents possess less quantity of type II muscle fibres in the vastus lateralis muscle compared to adults (Lexell, Sjöström, Nordlund, & Taylor, 1992; Sjöström, Lexell, & Downham, 1992) and have a reduced ability to utilize these higher-threshold motor units (Cohen et al., 2010; Dotan et al., 2012) which are more responsive to heavy resistance exercise (Hamada, Sale, MacDougall, & Tarnopolsky, 2000; Howarth & Kravitz, 2008). The combination of these factors may influence the ability of adolescent participants to derive benefits from heavy resistance exercise. However, these characteristics can be enhanced through training (Sale, 2002) and thus a trained adolescent population may be receptive to heavy resistance exercise.

This investigation measures the repeated sprint times of trained adolescent apprentice soccer players during a Repeated anaerobic sprint test with and without performing prior heavy resistance exercise. The study also investigates whether the effectiveness of the heavy resistance exercise to change sprint time correlates with the magnitude of 1 repetition max of individual participants. It is hypothesized that the heavy resistance exercise condition will result in a significant decrease in time compared to the corresponding sprint time collected without heavy resistance exercise. Total time taken to perform a repeated anaerobic sprint test is also thought to be significantly reduced follow heavy resistance exercise. There will also be a positive correlation between individual 1 repetition max and difference between with and without heavy resistance exercise sprint times.

2. Methods

Sixteen adolescent male apprentice soccer players participated in this investigation (age 17.1 ± 0.65 years; height 182.6 ± 8.9 cm; weight 77.8 ± 8.2kg). Participants were deemed athletically trained as they trained twice a day (90 - 120 min per session), five days a week (Smith, 2012). All participants wore suitable running shoes and the same club issue training kit (t-shirt, shorts and socks) to alleviate possible variability within the testing procedures. Each participant had a minimum of 6 months experience in performing back squats, the task utilised for the initiation of post-activation potentiation. All participants were informed about the procedures and any potential risks involved within the study; parental written consent was obtained before participation. Participants were also informed of their right to withdraw from the study at any time. The ethics board at the University Centre, North Lindsey College, approved this study.

Each participant completed a repeated anaerobic sprint test on two separate occasions. The repeated anaerobic sprint test was used as it is a reliable and simple field test to measure repeated sprint ability (Zacharogiannis, Paradisis, & Tziortzis, 2004). Prior to each repeated anaerobic sprint test, an identical 10-minute moderate intensity warm up consisting of jogging and dynamic stretches was performed. repeated anaerobic sprint tests were then carried out following the warm up alone (control) and after the warm up with additional heavy resistance exercise. The order that the tests were completed was counterbalanced for each participant. Each test was carried out at the same time on two subsequent Wednesdays to ensure adequate recovery from a competitive fixture on the previous Saturday. This also maintains test validity and reliability with regards to any influence of circadian rhythms and diurnal variation (Drust, Waterhouse, Atkinson, Edwards, & Reilly, 2005). Prior to each repeated anaerobic sprint test, participants were told not to partake in any exhaustive exercise in the preceding 24 hours of testing. They were also told to eat and drink the same during the 24 hours before each test. This included the avoidance of food and caffeine 2 hours prior to the testing procedure. This was verbally confirmed by each participant.

The repeated anaerobic sprint test was conducted on an outdoor 3rd generation Astroturf surface to eliminate possible variance in underfoot conditions. The procedure for the repeated anaerobic sprint test without heavy resistance exercise followed those reported in the literature (Zacharogiannis et al., 2004). Each participant was required to perform a maximal linear sprint for 35 meters. Ten seconds recovery time was then observed before the next 35 metre sprint began in the opposite direction; six sprints were conducted in total. Participants were given loud vocal encouragement throughout the repeated anaerobic sprint test and were instructed to perform each sprint in an all-out manner without any consideration towards conservation of energy and to avoid pacing strategies. To measure the times for each sprint, two electronic single beam timing gates (Brower Timing, Utah, USA) were used. The first gate was positioned on the start line and the second positioned on a line 35 metres away. Participants started each sprint by placing their toes against the line as directed by Ellis et al. (2000) in an attempt to assure the same starting body position and location for each sprint. Such consideration aimed to minimise the degree of momentum developed before the start of the action which effects the reliability of the data obtained (Duthie et al., 2006). This position was visually monitored by the investigators.

For the repeated anaerobic sprint test with the heavy resistance exercise, 91% of each participant's 1 RM was calculated for a back squat movement. The back squat was utilised as it activates the quadriceps muscle group, which generates power and contributes to running speed (Doscher, 2009; Newman, Tarpenning, & Marino, 2004). 91% 1 repetition max was used during the squat movement as it has been shown by Bevan et al. (2010) to be effective in eliciting improved linear sprint performance. One repetition max values were determined during a pre-test executed 7 days prior to conducting any repeated anaerobic sprint test. To maintain reliability and validity in the back squat protocol, a goniometer was used to accurately measure a 90 degree knee flexion angle at the bottom of a practice squat exercise. This was checked by the investigator and a wooden box was adjusted behind the participant so that at 90 degree knee flexion their buttocks touched the box, letting them know that they had completed the downward phase of the movement. Participants then extended their legs until they were straight. The procedure for calculating each participant's 1 repetition max started with the participant warming up with a light resistance exercise. Each participant performed between 5-10 back squat repetitions with a self-selected load using a standard 20kg Olympic lifting bar and free weights. A 60 second rest period then commenced before participants repeated 5 lifts with between 5-10% additional load added to the previous weight of the bar. A further 2 minute rest period was then observed prior to adding an additional 5-10% to the bar and completing another 3 repetitions. A further 3 minute recovery period was allowed and an additional 5-10% load was added to the bar. This process was repeated until the participant failed to complete a 1 repetition max whilst maintaining proper technique (Beachle & Earle, 2008).

Prior to the heavy resistance exercise trial, 91% of each individual's 1 repetition max was lifted 3 times in the same manner as was described during the calculation of 1 repetition max. This was followed by a recovery period of 8 minutes before the repeated anaerobic sprint test protocol was performed. This was deemed an optimal recovery period length to help overcome the fatigue effects from the protocol whilst still maintaining the potential benefit that post-activation potentiation would offer (Bevan et al., 2010).

All statistical analyses were completed using IBM SPSS Statistics 21 (SPSS Inc., Chicago, IL). The difference in overall sprint time as well as the difference measured between corresponding sprints within the repeated anaerobic sprint test with and without heavy resistance exercise was analysed using paired t-tests. Pearson's correlations coefficients (*r*) indicated the level of agreement between participants' 1 RM and the difference in sprint time with and without heavy resistance exercise for each individual sprint. For all statistical tests, statistical significance was accepted at $p < 0.05$ and a 95% confidence interval was reported for all raw data presented from the difference tests. Cohen's d effect size (*d*) was determined for all paired t-tests performed and relative changes in performance are expressed as 95% confidence interval (CI) for the effect size. Hopkins' (2002) definitions of Cohen's d effect sizes identified those that were trivial (<0.2), small (0.2 – 0.6), moderate (0.6 – 1.2) and large (1.2 – 2).

3. Results

Significant differences were demonstrated between corresponding sprints within the repeated anaerobic sprint test. Sprints 1 ($p = 0.05$) and 2 ($p = 0.02$) were faster in heavy resistance exercise condition (5.09 (± 0.16) vs. 5.11 (± 0.16) and 5.36 (± 0.24) vs. 5.45 (± 0.26) seconds respectively) although no other paired differences were shown ($p \geq 0.21$). A statistically significant effect for total time was also observed where a decrease in time was observed with the heavy resistance exercise condition ($p = 0.01$; Table 1). Effect sizes for comparisons of time with and without heavy resistance exercise during the individual sprint were trivial ($d < 0.2$) for sprints 1, 3, 4, 5 and 6, as well as for the total time. The effect size for sprint 2 was small ($d = 0.36$).

The Pearson's correlation coefficients indicated small relationships between the 1 repetition max and difference in sprint time for each of the 6 sprints ($r = -0.16$ to 0.24) but none were statistically significant ($p > 0.05$; Figure 1).

4. Discussion

In the current study, trained adolescent participants performed heavy resistance exercise to investigate whether this intervention would reduce sprint times during a repeated anaerobic sprint test. A major finding of this study was that total time to complete the repeated anaerobic sprint test as well as sprint times within the repeated anaerobic sprint test were reduced with the heavy resistance exercise intervention. These observations are in line with previous study findings on single and multi-sprint performance (Okuno et al., 2013; Requena et al., 2011).

The observation of reduced running time with heavy resistance exercise has been associated with post-activation potentiation, a phenomenon described as leading to increased synaptic excitation within the spinal cord, resulting in an improved capacity for force generation and increased post-synaptic potential of the involved muscle groups (Lorenz, 2011; Rassier & Herzog, 2002). These physiological enhancements lead to intensified type II motor unit recruitment, increased actin-myosin cross bridge activity within muscle fibres and decreased inhibition of the Golgi apparatus (Chiu et al., 2003; Hilficker et al., 2007; Sale, 2002; Xenofondos et al., 2010) causing a more powerful contraction of the muscle and the observed improvement in anaerobic sprint speed. The improved performance in the adolescent population used in the present investigation is contrary to the findings reported in similar aged populations (Arabatzi et al., 2013; Till & Cooke, 2009). This finding may relate to the repeated sprint task being more sensitive to the physiological changes that occur than events such as squat and counter jump tasks. Alternatively, by the age of 20, up to 50% of certain quadricep muscles have been converted into type II fibre type (Lexell et al., 1992) which exhibit greater post-activation potentiation (Hamada et al., 2000) and are more receptive to heavy resistance exercise. Owing to the population being approximately 17 years of age and the trained nature of the participants, sufficient development of these characteristics may have been accelerated resulting in the greater responsiveness to heavy resistance exercise being shown. The reporting of chronological age may not have been the best indicator of the maturation state of the participants. Instead, biological age may have provided a better characterization of the participants used in this study.

Despite the benefit of overall sprint time being reduced following the heavy resistance exercise, it was only improvements in sprints 1 and 2 that contributed to this overall finding. Participants seemed to experience an inability for sustained improvements for the remaining sprints which is contrary to the findings of Okuno et al. (2013) seen during repeated 30 m sprints in trained adult handball players. It could be speculated that whilst appropriate for adult participants, the length of the recovery time between conditioning exercise and the sprints may have been too long, resulting in a higher rate of decay in the post-activation potentiation mechanism (Sale, 2002) and a less sustained improvement in sprint time for the adolescent athletes used. Likewise, despite their trained status, the age of the participants may mean that they still have insufficient number and conditioning of type II muscle fibres which are more responsive to heavy resistance exercise (Ausubel, 2002; Hamada, Sale, MacDougall, & Tarnopolsky, 2000; Howarth & Kravitz, 2008). Consequently, the type II fibres that are available are more heavily loaded and thus are fatigued more quickly following the initial sprints; they are then unable to sustain the improved sprint performance.

Hopkins (2000) suggested that effect size of 0.2 multiplied by the between subject standard deviation represents the threshold for the smallest worthwhile change for substantial sprint performance modification. When performing short maximal sprints over 10 to 40 m, typical error in the measurement has been shown to be between 1 and 2.6% (Buchheit & Mendez-

Villanveva, 2013; Duthie et al., 2006; Moir, Button, Glaister, & Stone, 2004) representing a good test, but which results in error that is much greater than the smallest worthwhile change for sprinting (Duthie et al., 2006). Because of this discrepancy, when using a single beam timing gate as utilised in the current investigation, there is only a marginal chance of reliably detecting a change of sufficient magnitude to be worthwhile in practical terms (Duthie et al., 2006). Owing to this error, it is possible that larger, more meaningful effects are actually experienced during repeated sprints following heavy resistance exercise. Use of a dual beam timing gate and strict starting procedures can lower this error substantially and increase the possibility to detect these differences in a future investigation (Duthie et al., 2006).

Application of the study results to real world scenarios may be problematic. The general moderate warm-up procedure used in both the experimental and control conditions is similar to that used in studies utilising the repeated anaerobic sprint test (Zagatto et al., 2009; Balciunas et al., 2006). However, the warm-up procedure may not have been as thorough as that found in real life settings and thus may not be deemed optimal for the repeated anaerobic sprint test. The addition of the heavy resistance exercise may therefore have enabled improvement to be made yet had a more intense warm up been implemented there may not have been the same trends observed due to less physiological capacity to benefit further following the heavy resistance exercise. This speculation however needs consideration in future research. Likewise the small changes in time following the heavy resistance exercise demonstrated by trivial and small effect sizes may also lead us to question the practical implications of such findings. However, such margins may be the difference in achieving the desired goal such as winning a race or getting to the ball before the opponent. Similarly, the larger changes experienced during the first and second sprints may act as a training stimulus for adolescent athletes potentially benefiting those in future repeated sprint events.

The magnitude of response to the heavy resistance exercise has also been shown to correlate with the absolute load magnitude lifted by the participant, whereby those who lift greater amounts tend to be more responsive to the intervention (Okuno et al., 2013). The statistical analysis revealed no significant correlations between difference in sprint time and 1 repetition max for any of the six sprints. This is contrary to both the study hypothesis and the evidence presented in the literature (Duthie, Young, & Aitken, 2002; Kilduff et al., 2008; Okuno et al., 2013; Young, Jenner, & Griffiths, 1998). This suggests that magnitude of load has a limited role when attempting to elicit post-activation potentiation in trained adolescent athletes.

5. Conclusions

Training for speed is an important consideration for many intermittent sports such as soccer, and data in the current investigation shows that overall repeated sprint speed in trained adolescent soccer players can be improved using heavy resistance exercise, which was the result of improved initial sprint speed. It is however, important to acknowledge, that the specific effect of using heavy resistance exercise in speed training is yet to be comprehensively studied. Similarly the level of change demonstrated in the current investigation may question the practical meaningfulness of the study findings.

Having only observed benefit of heavy resistance exercise for the first and second sprints and that there appears no relationship between the difference in sprint time with 1 repetition max magnitude, developing sustained improvements from heavy resistance exercise may relate to the biological age, muscle fibre type and overall muscle condition. This may influence the capacity to derive prolonged benefits for the heavy resistance exercise intervention. This lack of significant differences may also relate to issues in data reliability when using a single beam time gate and thus requires further investigation.

References

Arabatzi, F., Patikas, D., Zafeiridis, A., Giavroudis, K., Kannas, T., Gourgoulis, V., & Kotzamanidis, C. M. (2013). The post-activation potentiation effect on squat jump performance: age and sex effect. *Pediatric Exercise Science*, Nov, 13.

Ausubel, D. P. (2002). *Theory and problems of adolescent development* (3rd ed.). Lincoln, New England: Writers Club Press.

Balciunas et al., 2006

Beachle, T., & Earle, R (2008). *Essentials of strength training and conditioning* (3rd ed.). Illinois: Human kinetics.

Berning, J. M., Adams, K. J., DeBeliso, M., Sevene-Adams, P. G., Harris, C., & Stamford, B. A. (2010). Effect of Functional Isometric squats on vertical jump in trained and untrained men. *Journal of Strength and Conditioning Research, 24*, 2285-2289.

Bevan, H., Cunningham, D., Tooley, E., Owen, N., Cook, C., & Kilduff, L. (2010). Influence of post-activation potentiation on sprinting performance in professional rugby players. *Journal of Strength & Conditioning Research, 24,* 701-705.

Bishop, D., & Claudius, B. (2005). Effects of induced metabolic alkalosis on prolonged intermittent-sprint performance. *Medicine and Science in Sports and Exercise*, *37*, 759-767.

Buchheit, M. & Mendez-Villanveva, A. (2013). Reliability and stability of anthropometric and performance measures in highly-trained young soccer players; effect of age and maturation. Journal of Sport Science, 31 (12), 1332 – 1343.

Chatzopolous, D., Michailidis, C., Giannakos, A., Alexiou, K., Patikas, D., Antonopoulos, C., & Kotzamanidis, C. (2007). Post-activation potentiation effects after heavy resistance exercise on running speed. *Journal of Strength & Conditioning Research, 21*, 1278-1281.

Chiu, L., Fry, A., Weiss, L., Schilling, B., Brown, L., & Smith, S. (2003). Post-activation potentiation response in athletic and recreationally trained individuals. *Journal of Strength & Conditioning Research, 17*, 671-677.

Cohen, R., Mitchell, C., Dotan, R., Gabriel, D., Klentrou, P., & Falk, B. (2010). Do neuromuscular adaptations occur in endurance-trained boys and men? *Applied Physiology Nutrition and Metabolism, 35* (4), 471 – 479.

Delecluse, C. (1997). Influence of strength training on sprint running performance. *Sports Medicine, 24*, 147-156.

Doscher, W. (2009). *The art of sprinting: techniques for speed and performance*. North Carolina: McFarland & Company.

Dotan, R., Mitchell, C., Cohen, R., Klentrou, P., Gabriel, D., & Falk, B. (2012). Child-adult differences in muscle activation - a review. *Pediatric Exercise Science, 24* (1), 2 – 21.

Drust, B., Waterhouse, J., Atkinson, G., Edwards, B., & Reilly, T. (2005). Circadian Rhythms in sport performance – an update. *Chronobiology International, 22*, 21-24.

Duthie, G. M., Pyne, D. B., Ross, A. A., Livingstone, S. G., & Hooper, S. L. (2006). The reliability of ten-meter sprint time using different starting techniques. *Journal of Strength and Conditioning Research, 20* (2), 246-251.

Duthie, G. M., Young, W. B., & Aitken, D. A. (2002). The acute effects of conditioning contractions on jump squat performance: an evaluation of the complex and contrast methods of power development. *Journal of Strength and Conditioning Research, 16*, 530-538.

Ellis, L., Gastin, P., Lawrence, S., Savage, B., Buckeridge, A., Stapff, A., … Young, W. (2000). Protocols for the physiological assessment of team sport players. In C. Gore (Ed.), *Physiological test for elite athletes* (pp. 128 – 143). Champaign, IL: Human Kinetics.

Gourgoulis, V., Aggeloussis, N., Kasimatis, P., Mavromatis, G., & Garas, A. (2003). Effect of submaximal half-squats warm-up program on vertical jumping ability. *Journal of Strength and Conditioning Research, 17,* 342-344.

Hamada, T., Sale, D. G., Macdougall, J. D., & Tarnopolsky, M. A (2000). Post-activation potentiation, fibre type, and twitch contraction time in human knee extensor muscles. *Journal of Applied Physiology, 88,* 2131-2137.

Hilfiker, R., Klaus, H., Lorenz, T., & Marti, B. (2007). Effects of drop jumps added to the warm-up of elite sport athletes with a high capacity for explosive force development. *Journal of Strength and Conditioning Research, 21,* 550-555.

Hodgson, M., Docherty, D., & Robbins, D. (2005). Post-activation potentiation. *Sports Medicine, 35,* 585-595.

Hopkins, W. G. (2000). Measurement reliability in sports medicine and science. *Sports Medicine, 30,* 1-15.

Hopkins, W. G. (2002). A scale of magnitudes for effect statistics. In: A New View of Statistics. Retrieved from http://newstats.org/effectmag.html

Howarth, R., & Kravitz, L. (2008). Post-activation potentiation: A brief review. *IDEA Fitness Journal*, 21-23.

Khamoui, A., Brown, L., Coburn, J., Judelson, D., Uribe, B., Nguyen, D., … Noffal, G. (2009). Effect of potentiating exercise volume on vertical jump parameters in recreationally trained men. *Journal of Strength & Conditioning Research, 23,* 1465-1469.

Kilduff, L. P., Owen, N. J., Bevan, H. R., Benett, M. A., Kingsley, M. I. C., & Cunningham, D. J. (2008). Influence of recovery time on post-activation potentiation in professional rugby players. *Journal of Sports Science, 26,* 795-802.

Laxell, J., Sjöström, M., Nordlund, A. S., & Taylor, C. C. (1992). Growth and development of human muscle: a quantitative morphological study of whole vastus lateralis from childhood to adult age. *Muscle and Nerve, 15* (3), 404 – 409.

Linder, E., Prins, J., Mutlata, N., Derenne, C., Morgan, C., & Solomon, J. (2010). Effects of pre-load 4 repetition maximum on 100-m sprint times in collegiate women. *Journal of Strength & Conditioning Research, 4,* 1184-1187.

Lorenz, D. (2011). Postactivation potentiation: An introduction. *The International Journal of Sports Physical Therapy, 6,* 234-240.

Moir, G., Button, C., Glaister, M., & Stone, M. H. (2004). Influenceof familarisation on the reliability of vertical jump and acceleration sprinting performance in physically active men. *Journal of Strength and Conditioning Research, 18,* 276 – 280.

Needham, R., Morse, C., & Degens, H. (2009). The acute effects of different warm up protocols on anaerobic performance in elite youth soccer players. *Journal of Strength & Conditioning Research, 23,* 2614-2620.

Newman, M., Tarpenning, K., & Marino, F. (2004). Relationships between isokinetic knee strength, single-sprint performance and repeated sprint ability in football players. *Journal of Strength & Conditioning Research, 18,* 867-872.

Okuno, N., Tricoli, V., Silva, S., Bertuzzi, R., Moreira, A., & Kiss, M. (2013). Post-activation potentiation on repeated sprint ability in elite handball players. *Journal of Strength & Conditioning Research, 27,* 662-668.

Rassier, D., & Herzog, W. (2002). Force enhancement following an active stretch in skeletal muscle. *Journal of Electromyographic Kinesiology, 12,* 471-477.

Requena, B., de Villerreal, E. S. S., Gapeyeva, H., Ereline, J., Garcia, I., & Paasuke, M. (2011). Relationship between post-activation potentiation of knee extensor muscles, sprinting and vertical jumping performance in professional soccer players. *Journal of Strength & Conditioning Research, 25,* 367-373.

Robins, D. (2005). Post-activation potentiation and its practical applicability: A brief review. *Journal of Strength and Conditioning Research, 19,* 453-458.

Sale, D. (2002). Post-activation potentiation: role in performance. *British Journal of Sports Medicine, 38,* 386-387.

Sjöström, M., Lexell J., & Downham, D. Y. (1992). Difference in fibre number and fibre type proportion within fascicles. A quantitative morphological study of whole vastus lateralis muscle from childhood to old age. *The Anatomical Record, 234* (2), 183 – 189.

Smith, C. (2012). *The effects of a postactivation potentiation warm up on subsequent sprint performance* (Unpublished doctoral dissertation). University of Utah, Utah.

Till, K., & Cooke, C. (2009). The effects of post-activation potentiation on sprint and jump performance of male academy soccer players. *Journal of Strength & Conditioning Research, 23,* 1960-1967.

Van Praagh, E., & Dore, E. (2002). Short-term muscle power during growth and maturation. *Sports Medicine, 32* (11), 701 – 728.

Weber, K., Brown, L., Coburn, J., & Zinder, S. (2008). Acute effects of heavy load squats on consecutive squat jump performance. *Journal of Strength & Conditioning Research, 22,* 726-730

Xenofondos, A., Laparidis, K., Kyranoudis, A., Galazoulas, C., Bassa, E., & Kotzamanidis, C. (2010). Postactivation potentiation: Factors it and the effect on performance. *Journal of Physical Education and Sport, 28,* 32-38.

Yetter, M., & Moir, G. (2008). The acute effects of heavy back and front squats on speed during 40 meter sprint trials. *Journal of Strength & Conditioning Research*, 22, 159-165.

Young, W. B., Jenner, A., & Griffiths, K. (1998). Acute enhancement of power performance from conditioning contraction squats. *Journal of Strength and Conditioning Research, 12*, 82-84.

Zacharogiannis, E., Paradisis, G., & Tziortzis, S. (2004). An evaluation of tests of anaerobic power and capacity. *Medicine and Science in Sports and Exercise, 36*, S116.

Zagatto et al., 2009;