

Postactivation potentiation in elite young soccer players

Adriano Tilton^{1,*}, Emerson Franchini²

¹Sao Paulo Futebol Clube, President Laudo Natel Athletes Development Center, Cotia, Brazil

²Department of Sport, School of Physical Education and Sport, University of São Paulo, São Paulo, Brazil

The aim of this study was to investigate the acute effects of 16 different combinations to cause the postactivation potentiation (PAP) in elite young soccer players. Squat exercise in 4 different intensities (40%, 60%, 80%, and 100% one-repetition maximum [1RM]) was performed and its effects were evaluated in the performance of countermovement jump (CMJ), after 4 different recovery times (1, 3, 5, and 10 min). For this purpose, 25 young soccer players, underwent five experimental sessions. At the first session the control to determine 1RM in half-squat was carried out. The following four experimental sessions were comprised of four intensity combinations with four different recovery intervals in order to perform the CMJ test later, randomly determined and with 30-min interval between each combination. The conditions were compared using an analysis of variance with repeated measurements,

followed by Bonferroni test, using 5% significance level ($P < 0.05$). The different intensities investigated did not provide significant increases in CMJ height, but significant differences were noted in recovery time, where, at CMJ maximum height, 1-min interval was better than after 3 min ($P < 0.05$), 5, and 10 min ($P < 0.001$). On the average jump performances, 1-min interval resulted in better results ($P < 0.001$) compared to other intervals. The 10-min recovery resulted in poorer performances compared to the other intervals ($P < 0.001$). Our results indicate that regardless the intensity used in the half-squat exercise with elite young soccer players, the 1-min recovery time was more appropriate to promote an increase in vertical jump.

Keywords: Young, Soccer players, Postactivation Potentiation


INTRODUCTION

The training of young soccer players has undergone considerable changes in the last decade, as result of studies related to the understanding of the determining motor needs in the match. The development of the physical training and the tactical organization of these young soccer players leads to a high energy demand during the competition (Pereira Da Silva et al., 2007) and matches that are increasingly intense (Maio Alves et al., 2010). According to Pereira Da Silva et al. (2007), the training concepts applied in adult players can also be applied to the younger, once the match patterns of both are proportionally similar. However, the physical stress of young players during the soccer match reduces the capacity of the stretch-shortening cycle, resulting in the diminution of performance in intense, decisive actions such as jumps and sprints, especially in the end of the match (Oliver et al., 2008).

The resistance and plyometric trainings have proven to be fundamental for the conditioning of athletes who need high explosive

performance (Mitchell and Sale, 2011) and these exercises are more effective when combined in the same session than when carried out separately (Kotzamanidis et al., 2005). For this reason, many professionals use the combined training, also called complex training, in which the resistance exercise is performed before a sport-specific explosive movement with similar biomechanical characteristics (Hodgson et al., 2005).

The efficiency of this type of training is possibly due to the success in the handling of the so-called postactivation potentiation (PAP), which consists on the acute increase in the skeletal striated muscle ability to produce strength after the conditioning activity (Hamada et al., 2000a). The possible physiological mechanism responsible for the PAP involves the myosin light chains, which are phosphorylatable, and whose main function is to change the sensitivity of the cross-bridges according to the phosphorylation state (Sweeney et al., 1993). Another possible mechanism involves neural effects, once, according to Gullich and Schmidtbleicher (1995), the accumulation of the action potentials in neuromuscular plaque

*Corresponding author: Adriano Tilton  <http://orcid.org/0000-0001-8330-3776>
Sao Paulo Futebol Clube, President Laudo Natel Athletes Development Center,
Avenida Doutor Odair Pacheco Pedroso, 1700, Cotia, 06717-642, Brazil
Tel: +55-11997644871, Fax: +55-1142431318, E-mail: atilton1@hotmail.com
Received: January 20, 2017 / Accepted: April 10, 2017

This is an Open Access article distributed under the terms of the Creative Commons Attribution Non-Commercial License (<http://creativecommons.org/licenses/by-nc/4.0/>) which permits unrestricted non-commercial use, distribution, and reproduction in any medium, provided the original work is properly cited.

increases the H-reflex amplitude, although such hypothesis has not been confirmed by Hodgson et al. (2005). From the practical point of view, the acute PAP manipulation, whatever its mechanism, would provide a more effective preparation before a session with emphasis on plyometrics.

The relationship between fatigue and PAP mechanism must be understood in order the recovery, to be prescribed before the power performance, be the best possible (Needham et al., 2009). In fact, the PAP response depends on the interactions between exercise intensity, number of repetitions and recovery interval. It is the combination of these factors that leads to a positive or negative influence on the power performance, such as the vertical jump (Mangus et al., 2006). Literature shows that there is not standardization of these factors, and according to Sale (2002), the diversity of protocols (intensity, volume, and contraction type), recovery periods, training levels, types of fiber and specificity of the training are responsible for the discrepancies in the research results.

It is known that the existing studies did not directly examine the PAP phenomena and the induction protocols, what makes difficult its exploration for the performance improvement (Robbins, 2005).

A single study carried out with young soccer players, conducted by Needham et al. (2009), verified the acute effect of different warm-up protocols (static and dynamic stretches, and the inclusion of the squat exercise with 20% of the body mass) in the execution of jumps and their different responses in different recovery times, concluding that the inclusion of resistance exercise increased the ability to jump with its peak after 3 min of execution. Since there is no standardization of the appropriate training load and recovery time to obtain a positive PAP response, the purpose of the present study was to verify the PAP response to different intensities of exercise and after different recovery times. Thus, the study intended to describe the intensity and the ideal recovery time for acute improvement in the power performance of elite young soccer players. The hypothesis of the present work was that the higher loads in the half-squat exercise and longer recoveries (5–7 min) would result in a greater PAP in elite young soccer players, thus making possible the increase of performance as result of the application of complex training methods.

MATERIALS AND METHODS

Subjects

The sample was composed of twenty five soccer athletes, members of youth categories of São Paulo Football Club, male (mean \pm standard deviation: age, 16.3 ± 0.6 years old; body mass,

70.7 ± 7.4 kg; height, 178.6 ± 6.0 cm; half-squat one-repetition maximum [1RM], 155 ± 23 kg). The athletes were individually evaluated for sexual maturation, according to Tanner (1962) protocol, by the club physician. Considering the pubic hair (P) and genital development (G) one athlete was classified as G2P2, one athlete as G2P3, six athletes as G3P3, four athletes as G3P4, five athletes as G4P3, six athletes as G4P4, one athlete as G5P3, and one athlete as G5P5. All the subjects participated voluntarily in this study and, after being informed on the procedures, they as well as those responsible by them signed an informed consent form. This study was approved by the Research Ethics Committee of the Federal University of São Paulo (Unifesp) (No. 1702/10) according to the standards of the law 196/96 of the Brazilian National Health Council for research involving human beings.

Experimental procedures

This study was conducted in a space exclusively reserved for the execution of tests at the President Laudo Natel Athletes Development Center located in the city of Cotia (Sao Paulo), where the youth categories training occur. The soccer players have been training for two or more years and had accumulated, at least, one year of experience in strength training with the half-squat exercise, which was trained in two or three sessions per week. After 30 days (transition period, off season), the athletes underwent six weeks of adaptation, period after which the present study was conducted. In this phase of adaptation, besides the usual training, three familiarization sessions for the 1RM test were included. On the week following the adaptation, the 1RM test was carried out and, over the following 4 weeks, the experimental sessions for collection of data on PAP were carried out. The interval between an experimental session and the other was of 1 week, since the normal activities of the soccer players occurred normally, so that between the last training session and the beginning of the tests a 48-hr rest period was given, in order the recovery was appropriate.

The combination of training loads with recovery times generated 16 experimental sessions that were randomly grouped in blocks of four combinations by evaluation session, with a 30-min rest interval between the sessions in the same day. This interval was necessary in order the effects of PAP were dissipated and thus a possible cumulative effect was minimized. The soccer players performed the half-squat exercise at the following 1RM percentages: 40%, 60%, 80%, and 100%. In each percentage, different numbers of repetitions were performed, as follows: at 40% 1RM, six repetitions; at 60% 1RM, four repetitions; at 80% 1RM, three to four repetitions; at 100% 1RM, one repetition. In each load percent-

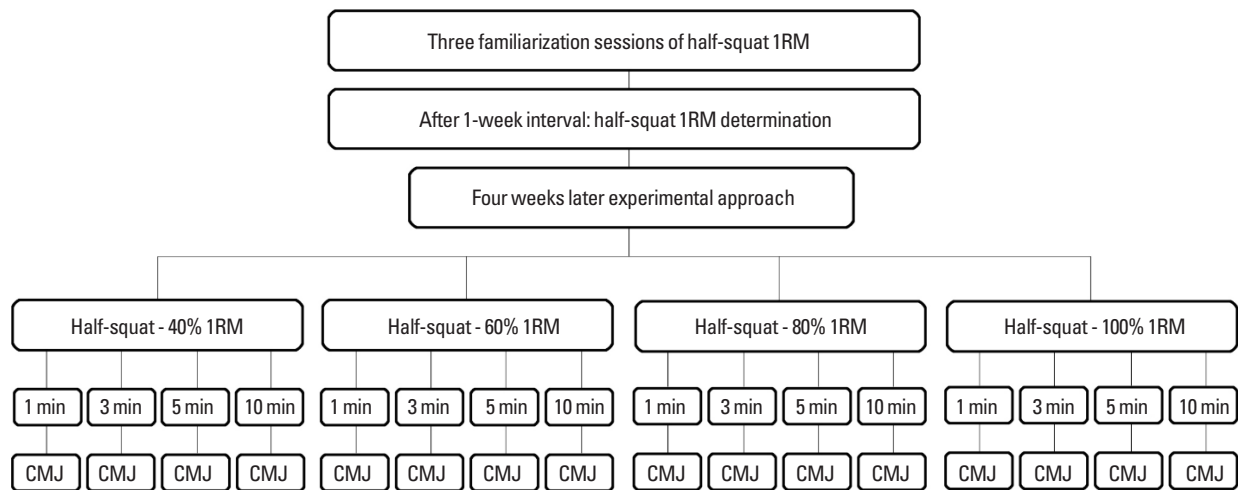


Fig. 1. Experimental design. 1RM, one-repetition maximum; CMJ, countermovement jump.

age, different recovery times were performed: 1, 3, 5, and 10 min. The Fig. 1 demonstrates in a schematic way the study design.

Repetition maximum protocol

Before the beginning of the test, the subjects performed a warm-up consisting of aerobic continuous cycling exercise for 5 min, 10 repetitions of unloaded half-squat, five repetitions at 50% of estimated 1RM and three repetitions at 70% of estimated 1RM, with 3-min recovery intervals between them. Next, after 3-min recovery, the athletes performed the half-squat exercise until they reached the 1RM load (maximum weight with which a single lift was performed with appropriate technique, without concentric failure). The attempts to determine 1RM were restricted to a maximum of five attempts and the interval between them was 3 min (Brown and Weir, 2001).

Vertical jump test

For the performance of CMJ test, the athletes were positioned on a small pressure sensitive contact mat of the Axon Jump and the software Axon Jump 4.0 (Axon Bioingeniería Deportiva, Buenos Aires, Argentina) were used. After the commands “prepare” and “go,” the subjects flexed the hip, ankle and knee joints at 90° and then extend them, at the highest possible speed, to perform the jump. The countermovement performed aimed to take advantage of the elastic energy that is accumulated in the quadriceps femoris. Three attempts, with 15-sec interval, were performed for each subject and the values considered were the highest reached and the average of the three attempts (Komi and Bosco, 1978).

Statistical analysis

In this study, the analysis of variance (ANOVA) with repeated measurements was used, considering the athletes as randomized blocks, using the variables intensity, time interval and interaction of intensity and time interval for the construction of the model. When there was significant difference detected by ANOVA the Bonferroni post hoc was applied. The effect size was calculated and the significance level adopted was $P < 0.05$.

RESULTS

For the CMJ maximum height (Table 1) there was an effect of time ($F = 32.1$, $P < 0.001$, $\eta^2 = 0.25$), with the values recorded after 1-min interval being above those after 3 min ($P = 0.005$), 5 and 10 min ($P < 0.001$ for both comparisons). Additionally, the values in 3 min were above those obtained after 10 min ($P < 0.001$). The values after 5 min were above those observed after 10-min interval ($P = 0.003$).

Similar results were observed for the CMJ mean height (Table 1) regarding the effect of time ($F = 32.7$, $P < 0.001$, $\eta^2 = 0.25$), with higher values after 1-min interval in relation to all other interval periods ($P < 0.001$ for all comparisons). Additionally, the values after 10 min were below those measured in 3 and 5 min ($P < 0.001$ for both comparisons).

DISCUSSION

The main findings of the present study were that the performance of half-squat with different intensities (40%, 60%, 80%,

Table 1. Maximum and mean values of countermovement jump for each 1RM intensity and recovery time

Intensity of 1RM	Recovery time (min)	Maximum height (cm)	Mean height (cm)
40%	1 ^{abe}	41.2±4.0	40.0±3.7
	3 ^{cf}	40.4±4.6	39.2±4.4
	5 ^{df}	40.2±4.3	39.1±4.3
	10	39.1±4.8	38.0±4.4
60%	1 ^{abe}	41.9±5.4	40.7±5.1
	3 ^{cf}	40.2±3.8	39.0±4.0
	5 ^{df}	39.9±4.5	38.9±4.5
	10	39.2±4.8	38.0±4.7
80%	1 ^{abe}	41.5±4.8	40.4±4.8
	3 ^{cf}	41.1±4.9	39.6±4.7
	5 ^{df}	40.5±4.2	39.6±4.3
	10	39.5±4.5	38.4±4.4
100%	1 ^{abe}	42.4±4.6	41.1±4.8
	3 ^{cf}	41.1±5.2	39.9±5.1
	5 ^{df}	39.8±5.3	38.7±5.2
	10	39.1±4.3	38.2±4.2

Values are presented as mean ± standard deviation.

1RM, one-repetition maximum.

^aEffect of time at maximum height: 1 > 3 min ($P=0.005$). ^bEffect of time at maximum height: 1 > 5 and 10 min ($P<0.001$). ^cEffect of time at maximum height: 3 > 10 min ($P<0.001$). ^dEffect of time at maximum height: 5 > 10 min ($P=0.003$). ^eEffect of time at mean height: 1 > 3, 5, and 10 min ($P<0.001$). ^fEffect of time at mean height: 3 and 5 > 10 min ($P<0.001$).

and 100% of 1RM) did not provide significant differences in CMJ height, but it was observed that among the different recovery times (1, 2, 3, 4, 5, and 10 min), the shorter ones were more appropriate. The results suggest that regardless the intensity used as conditioning activity in the squat exercise, PAP conditions are reached with 1-min interval when compared to longer intervals in young soccer players.

The optimum recovery period for elite young soccer players was clearly defined, showing that 10 min is too long to take advantage of the benefits of PAP, since 1, 3, and 5 min would result in values above those observed after 10 min. The recovery time resulted in higher values in CMJ test after the shorter intervals. These data corroborate the studies of Baudry and Duchateau (2007), who, using electromyography in different moments as measurement method of the muscle activation, verified that with electrically induced contractions and ballistic contractions the torque development reached its peak value 1 min after the maximum voluntary contraction stimulus and it remained potentialized up to 5 min. Other study using plantar flexion through the evaluation with electromyography in nine physically active men with 1-year experience in resistance training showed that 6 sec of maximum iso-

metric contractions and subsequently isokinetic dynamometer at 180 degrees per sec, as evaluation after different recovery times (1, 2, 3, 4, 5, and 10 min), resulted in a significant improvement ($P<0.05$) in the torque within 1–3 min (Miyamoto et al., 2011).

Assuming that the types of muscle fibers have decisive influence in PAP (Hamada et al., 2000b), as well as the training level and time (Robbins, 2005), the hypothesis related to the level of specific chronic adaptations specified in the sport and their transference to other means of training came up. Considering the demands inherent in soccer, with intermittent characteristics, where each soccer player performs between 1,000 and 1,400 different activities in a match, with actions in maximum intensity (sprint) at every 90 sec and high-intensity running every 30 sec (Bangsbo et al., 1991; Reilly et al., 2000; Stølen et al., 2005), these adjustments would result in such condition of potentiation in short recovery intervals, in other words, the fatigue was dissipated faster than the potentiation (Sale, 2002), in subjects involved in this study.

Few works used dynamic conditioning activities and recovery times similar to those of the present study, and they present divergent results. The research carried out by Ferreira et al. (2012), using the bench-press exercise, compared the effect of different recovery intervals (1, 3, 5, and 7 min) after a set of 1RM load on power performance in repetitions at 50% 1RM. The results indicated a significant increase in the mean and peak power during the concentric phase after 7-min recovery when compared to control and 1-min recovery conditions. Jensen and Ebben (2003) investigated the effects of the practice of 5RM in the squat on the output in CMJ executed right after different recovery periods (10 sec, 1, 2, 3, and 4 min), but they did not find any effect on performance, observing immediate decrease in the output when the 10-sec interval was adopted.

Other research studies have found improvements in the performance of explosive actions between different recovery intervals, but, it is worth emphasizing that the methodologies are not similar to the current study, using isolate loads and different recovery times. A study conducted with rugby players using the squat exercise as conditioning activity verified the effect of 3RM in CMJ test after different recovery times (15 sec, 4, 8, 12, 16 min). The results demonstrated a significant improvement in CMJ after 4, 8, and 12 min and worsening after 15 sec and 16 min when compared to the control condition (Crewther et al., 2011). Other work conducted with sprinter swimmers verified the performance in CMJ after a set of 3 repetitions at 87% 1RM in the squat and different recovery times (15 sec, 4, 8, 12, and 16 min). The results indicated significant improvement in CMJ after 8 min and wors-

ening after 15 sec when compared to the control condition group condition (Kilduff et al., 2011). Kilduff et al. (2008) also conducted a study with rugby players, using the half-squat exercise (3 sets of 3 repetitions at 87% 1RM) with different recoveries (15 sec, 4, 8, 12, 16, 20, and 24 min) to verify the effect on the performance in CMJ test, demonstrating significant improvement ($P < 0.01$) at 8 min when compared to other times, and decrease with the 15-sec interval when compared to the control. The study of Mitchell and Sale (2011), conducted with eleven university rugby players with 1-year experience in the resistance training verified that the height in CMJ was significantly increased 4 min after the performance of 5RM in the squat, compared to 8-min recovery.

Some studies compared different recovery times after conditioning activities, not verifying improvements in the performance of any variable. Jones and Lees (2003) compared the effect of intervals of 3, 10, and 20 min on the performance in CMJ after five squat repetitions at 85% 1RM, but they did not find significant increase in the jump heights. The work carried out by Comyns et al. (2006), with eighteen (nine women and nine men) anaerobic trained athletes (jumpers and sprinters), verified the effect of different recovery times (30 sec, 2, 4, and 6 min) in CMJ after the practice of 5RM in the squat exercise. The results demonstrated that there was no improvement of jump heights with different recovery times, but a significant decrease was found ($P < 0.05$) for the 30-sec and 6-min recoveries.

With regard to the load used in the present study to cause the PAP, it was verified that the intensity with different overloads (40%, 60%, 80%, and 100% 1RM) did not provide significant changes in the CMJ test heights. A hypothesis for not verifying acute effects in different intensities is that the methodology used in the current study may have been affected by the magnitude of the load, since different numbers of repetitions were performed in each percentage of intensity: 40% 1RM, six repetitions; 60% 1RM, four repetitions; 80% 1RM, two repetitions; and at 100% 1RM, one repetition. Only a study has compared the effect of the volume (12 repetitions with the load of 37% 1RM) with increased load (two repetitions with 50% 1RM after 3-min recovery, one repetition with 70% 1RM and after 4-min three repetitions with load of 90% 1RM). This study was conducted with eleven volleyball players, using the squat exercise. The subjects performed each variation in the exercise, and after 2-min recovery performed 10 CMJ with 2-min interval between each execution. The protocol with increased load produced a significant increase ($P = 0.034$) in the vertical stiffness during vertical CMJ (defined as the ability of changing from eccentric phase to concentric phase –

reaction force), and in relation to the jump height no differences were found (Moir et al., 2011).

It is worth noting that the methodology used in this work with different loads and recoveries, totaling 16 combinations, is the only that verified 4 intensity levels, with the purpose of finding the best training stimulus to young football players. Only two studies verified different intensities without dynamic actions to cause PAP. Brandenburg (2005), using the bench-press exercise with different intensities (five repetitions at 100% 5RM, 75% 5RM, and 50% 5RM), and control condition, after 5-min recovery intervals, with evaluation of three repetitions of ballistic bench-press exercises before and after different intensities. The author did not find significant differences between the potentiation protocols, a result similar to the present study. A study conducted with different means and intensities of warm-up, using the squat exercise has obtained results that diverge from the current study. Twelve male volleyball players were evaluated with seven stimuli of different characteristics and loads: (a) three sets of five jumps with load; (b) two sets of four repetitions at 80% 1RM and two sets of three repetitions at 85% 1RM; (c) two sets of four repetitions at 80% 1RM, two sets of two repetitions at 90% 1RM and two sets of one repetition at 95% 1RM; (d) three sets of five jumps in the drop jump determined by the optimal height of each subject; (e) specific warm-up, consisted of low intensity run, diverse displacements and four plyometric exercises with five jumps each; (f) three sets of five repetitions at 35% 1RM; (g) control condition. The conclusion of the study was that the use of activation protocols with dynamic and higher intensity actions (80%–95% 1RM), as well as specific warm-up protocols, provided higher acute positive effects on CMJ test output than in activation protocols that included lower intensity dynamic actions (Saez Saez de Villarreal et al., 2007).

Some investigations with experimental designs different from the current study did not find differences in protocols that involved jumps. Jones and Lees (2003) conducted an experiment with eight men with experience in resistance and plyometric training, performing five repetitions of squat exercise at 85% 1RM, followed by CMJ and did not find significant increase in jumps. Scott and Docherty (2004) did not find any improvement in the mean and maximum heights in vertical jump after the performance of 5RM in squat exercise. Jensen and Ebben (2003) investigated the effects of the performance of 5RM in the squat on CMJ output, not finding positive differences in the subsequent exercise. A study conducted by Khamoui et al. (2009), performed with sixteen recreationally strength trained men, investigated the

effect in the vertical jump test, through different volumes (one, two, three, four, and five repetitions) using 85% 1RM load in squat exercise, not finding significant differences.

However, other studies found improvement in the jump heights after conditioning activities. Young et al. (1998) determined, in a study with ten men with 1-year experience in half-squat, that the loaded countermovement jump with 19 kg can be accentuated with 5RM load. Gourgoulis et al. (2003) reported a significant increase (2.4%) in the CMJ test height after performing five progressive sets of two repetitions in the half-squat exercise at the following intensities 20%, 40%, 60%, 80%, and 90% 1RM. These studies illustrate that high loads in the squat exercise accentuated the jump performance, what in our intervention was not more effective to cause PAP. However, it is important to stress that such studies only compared the effects of a single load with the control condition, differently from the current study.

The main result of the present study was that the potentiation effects were noted in elite young soccer players in CMJ test, when it was preceded by the half-squat exercise, but its effects were not significant in relation to the loads used, different from the recovery time, where the shorter interval (1 min) resulted in improvements in jump heights when compared to longer intervals (3, 5, and 10 min).

In summary, our study indicates that the PAP effects in elite young soccer players were not improved in any of the intensities investigated. However, the coaches need to pay attention to the optimum interval time for the CMJ after the conditioning activities, since the 1-min recovery time was more appropriate. It is worth pointing out that to extrapolate the concepts of complex training with conclusions arising from studies in other sports to the soccer reality should be done with caution, especially because soccer is a sport that does not require a standard biotype neither a specific physical characteristic. Additionally, few investigations have been published concerning the effects of PPA in young soccer players. Other studies involving acute and chronic effects of PAP in young soccer players are extremely relevant to clarify such doubts.

CONFLICT OF INTEREST

No potential conflict of interest relevant to this article was reported.

REFERENCES

Bangsbo J, Nørregaard L, Thorsø F. Activity profile of competition soccer.

Can J Sport Sci 1991;16:110-116.

- Baudry S, Duchateau J. Postactivation potentiation in a human muscle: effect on the rate of torque development of tetanic and voluntary isometric contractions. *J Appl Physiol* (1985) 2007;102:1394-1401.
- Brandenburg JP. The acute effects of prior dynamic resistance exercise using different loads on subsequent upper-body explosive performance in resistance-trained men. *J Strength Cond Res* 2005;19:427-432.
- Brown LE, Weir J. ASEP procedures recommendation I: Accurate assessment of muscular strength and power. *J Exerc Phys Online* 2001;4:1-31.
- Comyns TM, Harrison AJ, Hennessy LK, Jensen RL. The optimal complex training rest interval for athletes from anaerobic sports. *J Strength Cond Res* 2006;20:471-476.
- Crewther BT, Kilduff LP, Cook CJ, Middleton MK, Bunce PJ, Yang GZ. The acute potentiating effects of back squats on athlete performance. *J Strength Cond Res* 2011;25:3319-3325.
- Ferreira SL, Panissa VL, Miarka B, Franchini E. Postactivation potentiation: effect of various recovery intervals on bench press power performance. *J Strength Cond Res* 2012;26:739-744.
- Gourgoulis V, Aggeloussis N, Kasimatis P, Mavromatis G, Garas A. Effect of a submaximal half-squats warm-up program on vertical jumping ability. *J Strength Cond Res* 2003;17:342-344.
- Gullich A, Schmidtbleicher D. Short-term potentiation of power performance included by maximal voluntary contractions [abstract]. In: Hakkinen K, Keskinen KL, Komi P, Mero A. editors. XVth Congress of the International Society of Biomechanics; 1995 Jul 2-6; Jyväskylä, Finland. International Society of Biomechanics; 1995:348-349.
- Hamada T, Sale DG, Macdougall JD. Postactivation potentiation in endurance-trained male athletes. *Med Sci Sports Exerc* 2000a;32:403-411.
- Hamada T, Sale DG, MacDougall JD, Tarnopolsky MA. Postactivation potentiation, fiber type, and twitch contraction time in human knee extensor muscles. *J Appl Physiol* (1985) 2000b;88:2131-2137.
- Hodgson M, Docherty D, Robbins D. Post-activation potentiation: underlying physiology and implications for motor performance. *Sports Med* 2005;35:585-595.
- Jensen RL, Ebben WP. Kinetic analysis of complex training rest interval effect on vertical jump performance. *J Strength Cond Res* 2003;17:345-349.
- Jones P, Lees A. A biomechanical analysis of the acute effects of complex training using lower limb exercises. *J Strength Cond Res* 2003;17:694-700.
- Khamoui AV, Brown LE, Coburn JW, Judelson DA, Uribe BP, Nguyen D, Tran T, Eurich AD, Noffal GJ. Effect of potentiating exercise volume on vertical jump parameters in recreationally trained men. *J Strength Cond Res* 2009;23:1465-1469.

- Kilduff LP, Cunningham DJ, Owen NJ, West DJ, Bracken RM, Cook CJ. Effect of postactivation potentiation on swimming starts in international sprint swimmers. *J Strength Cond Res* 2011;25:2418-2423.
- Kilduff LP, Owen N, Bevan H, Bennett M, Kingsley MI, Cunningham D. Influence of recovery time on post-activation potentiation in professional rugby players. *J Sports Sci* 2008;26:795-802.
- Komi PV, Bosco C. Utilization of stored elastic energy in leg extensor muscles by men and women. *Med Sci Sports* 1978;10:261-265.
- Kotzamanidis C, Chatzopoulos D, Michailidis C, Papaikovou G, Patikas D. The effect of a combined high-intensity strength and speed training program on the running and jumping ability of soccer players. *J Strength Cond Res* 2005;19:369-375.
- Maior Alves JM, Rebelo AN, Abrantes C, Sampaio J. Short-term effects of complex and contrast training in soccer players' vertical jump, sprint, and agility abilities. *J Strength Cond Res* 2010;24:936-941.
- Mangus BC, Takahashi M, Mercer JA, Holcomb WR, McWhorter JW, Sanchez R. Investigation of vertical jump performance after completing heavy squat exercises. *J Strength Cond Res* 2006;20:597-600.
- Mitchell CJ, Sale DG. Enhancement of jump performance after a 5-RM squat is associated with postactivation potentiation. *Eur J Appl Physiol* 2011;111:1957-1963.
- Miyamoto N, Kanehisa H, Fukunaga T, Kawakami Y. Effect of postactivation potentiation on the maximal voluntary isokinetic concentric torque in humans. *J Strength Cond Res* 2011;25:186-192.
- Moir GL, Mergely D, Witmer C, Davis SE. The acute effects of manipulating volume and load of back squats on countermovement vertical jump performance. *J Strength Cond Res* 2011;25:1486-1491.
- Needham RA, Morse CI, Degens H. The acute effect of different warm-up protocols on anaerobic performance in elite youth soccer players. *J Strength Cond Res* 2009;23:2614-2620.
- Oliver J, Armstrong N, Williams C. Changes in jump performance and muscle activity following soccer-specific exercise. *J Sports Sci* 2008;26:141-148.
- Pereira Da Silva N, Kirkendall DT, Leite De Barros Neto T. Movement patterns in elite Brazilian youth soccer. *J Sports Med Phys Fitness* 2007;47:270-275.
- Reilly T, Bangsbo J, Franks A. Anthropometric and physiological predispositions for elite soccer. *J Sports Sci* 2000;18:669-683.
- Robbins DW. Postactivation potentiation and its practical applicability: a brief review. *J Strength Cond Res* 2005;19:453-458.
- Saez Saez de Villarreal E, González-Badillo JJ, Izquierdo M. Optimal warm-up stimuli of muscle activation to enhance short and long-term acute jumping performance. *Eur J Appl Physiol* 2007;100:393-401.
- Sale DG. Postactivation potentiation: role in human performance. *Exerc Sport Sci Rev* 2002;30:138-143.
- Scott SL, Docherty D. Acute effects of heavy preloading on vertical and horizontal jump performance. *J Strength Cond Res* 2004;18:201-205.
- Stølen T, Chamari K, Castagna C, Wisløff U. Physiology of soccer: an update. *Sports Med* 2005;35:501-536.
- Sweeney HL, Bowman BF, Stull JT. Myosin light chain phosphorylation in vertebrate striated muscle: regulation and function. *Am J Physiol* 1993;264(5 Pt 1):C1085-1095.
- Tanner JM. Growth at adolescence. 2nd ed. Oxford: Blackwell Scientific Publications; 1962.
- Young WB, Jenner A, Griffiths K. Acute enhancement of power performance from heavy load squats. *J Strength Cond Res* 1998;12:82-84.