Review Paper

Post activation potentiation (PAP) and its application in the development of speed and explosive strength in female soccer players: A review

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ABSTRACT

The presented review presents the results of current research on the use of PAP during resistance training of soccer players. Researchers who have examined the mechanism behind PAP following complex strength training, have established a relationship between post-activation potentiation and improvements in speed and explosive strength of athletes. Most of the presented papers in this review have confirmed the effectiveness of PAP in eliciting performance in tasks requiring speed, jumping ability and agility in soccer players. These studies were discussed in detail in terms of research groups, methods, training means and study results. Many of these publications have also considered the aspect of rest intervals between the conditioning exercise and the subsequent explosive activity. Most authors indicate the necessity to individualize the time of the rest interval, depending on the athletes training status, strength level and most of all on the intensity and volume of the conditioning exercise. Some scientists have also attempted to incorporate PAP into warm-up protocols, especially prior to speed and power training sessions. A two-way analysis of the impact of PAP, separately on sprint speed and power of the players. The focus was on demonstrating the positive or negative impact of activating exercises on the two variables discussed. The last part of the paper presents the conclusions drawn based on the results of the studies and suggests the objectives of future research. Most publications have documented the results for male participants, whereas little data is available regarding the use of PAP in female soccer players. **Keywords:** Explosive strength; Complex training; Female athletes; Sports performance.

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THE CONCEPT OF POST-ACTIVATION POTENTIATION

Post-activation potentiation (PAP) is the phenomenon which occurs in muscles due to activation of muscle fibres through strength training. Post-activation of muscle fibres has a direct effect on the rate of force development or the ability to generate force in a short period of time (Hodgson et al. 2005). In practice PAP has been achieved by complex training, which involves a combination of a heavy loaded resistance exercise, followed by an explosive activity specific for a particular sport discipline. There are four possible mechanisms responsible for PAP. Two of them are well documented, while the other two are hypothetical. One includes the phosphorylation of myosin light chains resulting from the initial muscle activity, which render the actin and myosin molecules more sensitive to Ca2+ availability, that increases the rate of force development). The other mechanism of PAP includes neural factors, such as the excitability of α-motoneurons being responsible for increased contractile performance after previous muscular activity. The heavy loaded exercise increases higher order motoneuron recruitment, what may increase fast twitch fibre contribution, and enhance performance in subsequent explosive activities (Tillin & Bishop 2009, Yetter & Moir 2008). The third mechanism underlying PAP involves changes in penetration angle. Some research has confirmed that smaller penetration angles have a mechanical advantage with respect to force transmission to the tendon. The fourth, possible mechanism of PAP considers the increased resting binding of titin to actin, decreasing its free length and increasing muscle stiffness (Herzog et al. 2016).

Gago et al.(2017) investigated differences in the magnitude and timing of plantar flexor PAP between a flexed and an extended knee joint position and as a consequence, the amplitude and duration of gastrocnemius PAP contribution to overall plantar flexor twitch enhancement. Chen et al. (2017) attempted to determine whether two types of comprehensive training composed of vibrations would improve the individual phenomenon of power after activation (PAP) for each athlete in the team. Several changes have been observed in the last year in the approach to strength training in various sports, including team sports. Studies have examined the use of post-activation potentiation effect in speed training for sprinters and the development of explosive strength (Tsimachidis et al. 2013), in the squat jump for eliciting maximal power in ski jumpers (Golas et al. 2017a), and for explosive activities in other competitive sports (Golas et al. 2016, Golas et al. 2017b). From the standpoint of modern soccer training, this aspect is especially significant due to the importance of speed and explosive strength in this and other team sport games. In respected databases, such as the Web of Science, Core Collection, Scopus, Ebsco (Sport Discus), LWW Sport Package, Science Direct and the most popular and accessible database of cited scientific papers Google Scholar, relatively few publications have dealt with the use and effectiveness of PAP in soccer.

Table 1. Results of research on the impact of PAP on speed and strength of soccer players.

Date	Authors	Experimental group	PAP procedure	Testing parameters	PAP effect
2011	Requena et al.	14 M soccer players (20 ±3.6 yrs)	10-s isometric MVC of knee extensor muscles (electrically evoked)	CMJ 15-m sprint speed test SJ	E (VJ) E E (VJ)
2011	Stieg et al.	17 F soccer players (18.94±0.74 yrs)	CMJ followed by 0, 3, 6, 9, or 12 DJ	VJ rGRF	NE NE
2015	Vanderka et al.	13 M soccer players (17-19 yrs)	40-m sprint test before and after 9 m seated rest (control protocol) 40-m sprint test before and after 2x6 rep. Half squat Jump (load eliciting maximum power)	0-20m sprint speed test 20-40m sprint speed test	NE NE

2014	Garcia-Pinillos et al.	30 M soccer players (15.9±1.43 yrs) – 13 C, 17 E	12-week CT (2 x week 1 isometric and 2 plyometric exercises without external loads)	VJ Kicking speed 5, 10, 20 and 30-m sprint speed test Agility (BAT)	E E E E
2017	Nealer et al.	24 F soccer players (19-22 yrs) 11 recreational (R), 13 collegiate athletes (CA)	5 sessions: dynamic warm up + 1 x 20 m sprint (with 5 m splits) at 30% bodyweight assistance (BWA) + 30 s, 1, 2, or 4 minutes rest in random order + 1 x bodyweight sprint (no BWA)	0-20 m sprint speed test (30 s., 1, 2, 4 min. rest) 0-5 m sprint speed test (30 s., 4 min rest) 0-5 m sprint speed test (1, 2 min rest)	NE NE NE NE
2013	Mola J et al.	22 M soccer players (23±4.5 yrs) – 11 C, 11 E	C + E: Warm up + CMJ + 10 min recovery C: CMJ at 15 s, 4, 8, 12, 16 and 20 min rest E: 3xRM squat + CMJ at 15 s, 4, 8, 12, 16 and 20 min rest	CMJ Peak power Jump-height	E (n=3 after 4 min rest, n=1 after 12 min rest, n=2 after 16 min rets)
2007	Chatzopoulos et al.	15 M team game players (18-3 yrs)	High Resistance Squat: 10 single reps of 1RM	0-10 m sprint speed test with 3 min rest 0-30 m sprint speed test with 3 min rest 0-10 m sprint speed test with 5 min rest 0-30 m sprint speed test with 5 min rest Summary	NE NE E E WE
2010	Alves J.V. et al.	23 M soccer players (17.4±0.6 yrs) : E1=9, E2=8, C=6	E1, E2: regular soccer training + 6-weeks Complex and Contrast Training (3stations: general exercise, multiform exercise and specific exercise with increasing load by 5% from 1RM 2 weeks) C: regular soccer training	0-5 m sprint speed test 0-15 m sprint speed test SJ	E E E
2017	Rhibi et al.	45 M amateur soccer players: PG (plyometric group)=15; IG (isometric group) = 15; CG (control group) = 15	PG: warm up + six hurdle jumps (1 × 4), squat jump to the front (1 × 4), and bilateral side to side hops on one leg (1 × 4) + 1 min rest interval between hop exercises IG: warm up + isometric exercise (wall-squat (4 × 10 s) + leaning against the wall with knees bent at approximately 90°(1 min rest interval between sets) + 10 s sit wall (1 × 4) + 10 s squat position (1 × 4)	SJT + 5, 10 and 15 recovery time 5JT + 5, 10 and 15 recovery time 5JT	E E E

			CG: warm up + no additional exercises		
2015	Low D. et al.	16 M soccer players (17.05 ± 0.65)	running-based repeated anaerobic sprint test with and without prior heavy resistance exercise of 91% of 1RM (back squat)	35 m speed sprint test	E
2009	Till K. & Cooke C.	12 M soccer players	4 warm up protocols in a crossover, randomized, and counterbalanced design: deadlift (5x1RM), tuck jump (5 reps), and isometric MVC knee extensions (3 reps for 3 s)	3 x 0-10 m and 0- 20 m sprint speed test 4, 5 and 6 min post-warm up) and 3 x VJ (7, 8 and 9 min post-warm up)	NE NE NE
2018	Nickerson B. et al.	12 M soccer players (21 ± 2.0 yrs)	3 x set of 3 repetitions of parallel back squat at 85% 1RM (1 x performed continuously), 2 x with 30- and 60-s rest int. between each repetition)	3 x 20-m sprint at 1-, 4-, 7-, and 10-minutes post exercise	E (with 30 s rest between reps of parallel back squat)
2018	Dello Iacono & Seitz	18 M amateur soccer players	Barbell Hip Trust + 85% load Barbell Hip Trust + optimal load	0-5 m sprint 15 s., 4 and 8 min. after activation 0-10 m sprint 15 s., 4 and 8 min. after activation 0-20 m sprint 15 s., 4 and 8 min. after activation	E E E

Effect: WE (weak positive effect); E (positive effect); NE (negative effect).

THE IMPACT OF PAP ON SPEED ABILITIES IN SOCCER

Apart from tactical and mental preparation, speed and strength training are among key components of the training process in soccer. During soccer competition, players perform numerous accelerations and decelerations. Therefore, endurance and strength training, including explosive strength, include key training objectives in physical fitness preparation of soccer players. In contemporary sport, including team sport games, the ability to generate high values of muscular power has a substantial effect on performance. The application of PAP in endurance and sprint training allows for a significant increase in speed and speed endurance during training and competition in soccer. This review considers the PAP effect regarding two key motor abilities in competitive soccer. First the benefits of PAP on different aspect of speed is evaluated, while in the second part of the manuscript the effectiveness of PAP on explosive strength is analysed.

The concept of speed in soccer is an umbrella term that refers to the speed of perception, prediction, anticipation, reaction, decision-making and movement. Speed is also essential for players at any position on the pitch, without exception. However, it is especially important for forwards. It is indisputable that fast defenders are also valuable players. During a match men's soccer match, forwards perform approximately 24 sprints at a speed of 30 km/h and more, midfielders about 17 sprints, while defenders perform 16 sprints. Furthermore, midfielders perform the most runs at low and medium intensity: 277 runs at a speed of 12-16 km/h and 127 runs at a speed of 16-21 km/h. For comparison, forwards perform 231 runs with low intensity and 120 runs with medium intensity, whereas defenders perform 210 and 106 runs with low and medium intensity, respectively (Bangsbo 1994). Percentage of sprints during a soccer match ranges from 10 to 18% during a match, which is a relatively low value. In contemporary soccer, tactical preparation of teams is comparable, whereas players are at a similar technical level (for a specific level of competition). The factor that offers an advantage over competitors is speed: greater speed means reaching the ball faster than the opponent, and as a consequence winning 1 on 1 battles. Scoring a goal or stopping the opponent's attack is often determined by the speed of either forwards or defenders (Chelly et al. 2009).

The study of Requena et al. (2011), examined the correlations between PAP in the knee extensors and speed and jumping abilities of soccer players. The study participants included 14 professional players aged 20.0±3.6 years. During the study, the participants performed 15 m sprints after the knee extensors were evoked by a 10s electrically stimulated maximal voluntary contractions (MVC). Based on the results, the authors concluded that the PAP effect in the knee extensors allowed for significant improvement of sprint speed of soccer players.

In the research of Vanderka et al. (2015) changes in sprint speed following half-squat jumps as the conditioning activity were not observed in soccer players. The study participants 25 subjects (12 track and field athletes and 13 soccer players). Test protocol, consisted of 40 m sprints, with measurements made at the 20 and 40 m mark. During the first stage of examinations, sprint speed was measured before and after a 9-minute recovery. In the second stage of evaluations, maximal power was measured after performing 6 repetitions of loaded half-squat jumps. The results revealed substantial improvements in sprint speed, but only in track and field athletes, not in soccer players. The authors of the paper linked the improvements in sprint speed with the conditioning level of the athletes and running technique.

Scientists from the University of Jaén in Spain described the effect of a 12-week isometric and plyometric contrast training (CT) program without additional external load on, sprinting speed of young soccer players (Garcia-Pinillos et al. 2014). The study participants included 30 youth soccer players divided into two groups: a control group (13 players) and an experimental group (17 players). In players from the experimental group, the test protocol was incorporated twice a week into a training routine. Additional training involved 1 isometric and 2 plyometric exercises without additional external load, whereas training volume for particular exercises was gradually increased. Before and after the 12-week training program, the following fitness variables were evaluated: CMJ, agility (Balsom Agility Test), running speed at 5, 10, 20 and 30 m, and kicking force. The results showed speed improvements in both groups of participants at all distances (5, 10, 20 and 30m sprints $p \leq 0.05$). The authors concluded that the use of adequate isometric-plyometric training in soccer players improves sprint speed abilities.

In contemporary soccer running speed seems to be a key component of success. The ability to suddenly accelerate helps players steal the ball and perform a successful attack or a proper defensive play. Therefore, the development of explosive strength in soccer players is a significant component of resistance training. The use of complex training with the PAP mechanism in resistance training is a unique and innovative approach. Nealer et al. (2017), who examined 24 female soccer players, attempted to establish the effect of varied recovery intervals between successive sprints on running speed. The athletes were divided into two groups: 11 recreational athletes and 13 collegiate athletes who participated in 5 training sessions. The research protocol was composed of a dynamic warm-up, 20 m sprint with bodyweight assistance (BWA), that reduced the effect of body weight by 30% and a random rest interval of (30 s, 1, 2 or 4 min), followed by another 20 m sprint with no BWA. In case of the 5 m sprints, female collegiate athletes showed significant improvements in speed after 1 min (1.15 ± 0.06 s) and 2 min rest intervals (2.16 ± 0.06). Therefore, the authors concluded, that the use of 1- or 2-minute rest intervals after a sprint at 30% BWA in elite female soccer players improves competitive speed at 5 m.

Chatzopoulos et al. (2007) and his colleagues conducted a research on the use of PAP effect in strength training in four team sports. The study participants were 15 amateur basketball, volleyball, handball and soccer teams. The aim of the study was to establish the effect of PAP induced by the resistance stimuli on the speed of 30 m sprints. An indirect measurement after running the 0-10 m split was also performed. The activating stimuli in this case was barbell squat with the load of 90% 1RM. Running tests were divided into 3 stages when sprint speed was measured 3 minutes before activation with resistance stimulus, 3 minutes after the training session and 5 minutes after the session. The use of the 3-minute rest between training and 10 m and 30 m sprints did not lead to improvements in speed of athletes. However, with the 5-minute rest, the results of sprints improved ($p < 0.05$) for both distances. The examinations led to the conclusion that the 5-minute rest in strength training with high load leads to expected improvements in speed of 10 m and 30 m sprints in players of various team sports, including soccer players.

Alves et al. (2010) analysed the effects of complex and contrast training (CCT) on sprint (5 and 15 m) in elite young Portuguese soccer players. The participants were 23 young players divided into 3 groups: two experimental groups (9 and 8 players) and one control group (6 participants). The experimental groups were involved in regular soccer training enhanced by a 6-week strength training program. The control group, apart from a standard soccer training, was not subjected to strength training. Strength training was composed of 3-element stations. The first step was to perform 6 repetitions of barbell squat with the load of 85% 1RM, and next the athletes performed high skipping over the distance of 5 m and, finally, they ran 5 m sprints. The second station was composed of 6 repetitions of calf extensions at 90% 1RM, followed by 8 vertical jumps and 3 ball header jumps. The third station included 6 repetitions of leg extensions in a sitting position at 80% 1RM, 6 jumps from the seated position and 6 drop jumps from a 60 cm platform, finished with a soccer heading jump. In the experimental groups, training load during strength training was increased by 5% 1RM every 2 weeks. Reduction of sprint times was observed for the distances of 5 and 15 m. The training protocol used in the study was aimed to improve sprint therefore, it should be applicable in soccer training for development of strength and speed during sprints performed by players.

The paper published by Low (2015) presented the findings from the study aimed at verification whether resistance training with high load would improve sprint speed in young soccer players (Low et al. 2015). The study examined 16 young players, who had performed barbell squats for at least 6 previous months. All the players taking part in the experiment performed two sprint tests during various sessions. In the first research sessions, a maximal individual load (1RM) for barbell squat was evaluated for each player. In the second and third session, players performed the repeated anaerobic sprint test on a treadmill with or without previous resistance training with 91% 1RM. Times were recorded for each of the six sprints and as a total time. The improvements in sprint times after resistance training were observed, although these benefits are not permanent as it is the case in adult soccer players.

The use of strength training in soccer training to improve speed and jumping abilities of players was also the focus of the tests described in the paper by Till and Cooke (2009). The researcher examined the PAP effect caused by both dynamic exercises and isometric maximum voluntary contraction (MVS) on players' speed during sprints and improvements in jump height. The study examined 12 soccer players. The PAP protocol was composed of a 5-minute warm-up (jogging), dynamic exercises, and performing 1 of 4 sets of recommendations followed by recovery (4-minute walk). The first of the four sets of recommendations did not include any activation exercises. The second included strength exercise (deadlift) performed with 5 repetitions with 5RM. The third set was plyometric training, composed of tuck jumps (5 repetitions). The last set of exercises included isometric maximum voluntary contraction of the knee extensors performed in the sitting position (3 repetitions for 3 second) for each leg. After a 4 minute rest the athletes underwent three 10 m and 20 m sprints (4, 5, and 6 minutes after the activation), with running time measured over the splits 0-10 m and 10-20m. Analysis of the results did not reveal a significant PAP effect on global speed during sprints after training protocol with dynamic and isometric exercises with previous warm-up protocol. However, high variability of individual performance was found among the athletes, which suggests that the use of PAP effect in soccer strength training should be approached individually.

The purpose of Nickerson's et al. study (2018) was to determine whether back squat cluster sets (CS) with different rest periods between repetitions affect the sprint performance in comparison to the traditional set of parallel back squats in 12 young soccer players. Participants performed the base sprint at 20 m before starting the strengthening exercise and after 1, 4, 7 and 10 minutes after PAP activating. The PAP protocol included 3 separate sessions. Each time a complex of strengthening exercises consisted of 1 set of 3 repetitions with 85% 1RM for a traditional parallel squat. However, once the set of 3 repetitions was performed continuously and the other 2 were performed with 30 s and 60 s of rest between each repetition. An improvement in the sprint speed was found at 20 m after the PAP protocol with 30 s of the rest between reps and with a 10 min. recovery period after activation. It means that such a PAP protocol can be used by soccer players, for example, during the warm-up in order to significantly improve sprint abilities during the first 10 minutes of match.

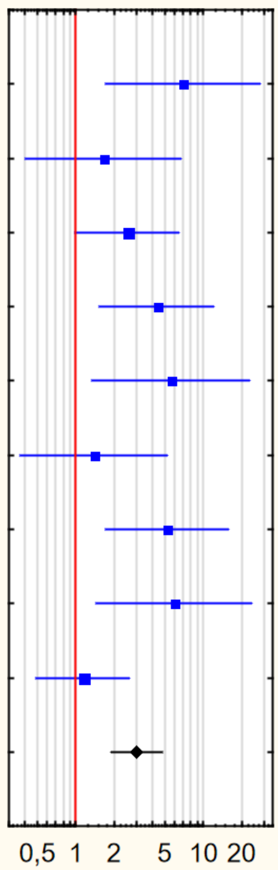
Dello Iacono & Seitz (2018) tested the impact of two PAP protocols based on Barbell Hip Thrust with a load of 85% and with the optimal load for power development on the speed of sprints in soccer players. In the experiment took part 18 athletes, who performed sprints on 5 m, 10 m and 20 m before using the PAP protocol and after 15 s, 4 min and 8 min after PAP training. A significant improvement in speed at all testing distances were observed after using a 4 and 8-minute recovery time in both PAP protocols, but the worst results were obtained in the 5 and 10 m tests after applying the 85% 1RM load and 15 s recovery rest interval. The best results at all three distances were obtained after using the protocol with optimal load for power development and 4 and 8-minute recovery intervals. This shows that very heavy, as well as optimal loads can induce a PAP response, but the optimal power loading protocol is better due to its higher efficiency.

Taking into account the above-mentioned research results, it should be stated that the use of strength soccer training based on PAP protocols can improve speed abilities of soccer plyers. However, the effect will depend on many factors, such as: the age of the players, the type of stimulus, the height of the load, the length of recovery time. Young soccer players respond better to stimuli, but the long-term effect is weaker than in older players. The squat seems to be a good activation exercise, yet the load should not exceed 85% of 1RM. It is also important to determine the appropriate intensity and volume of activating exercises. Good results are also obtained by using isometric-plyometric exercises. Considering recovery time, 4-8 min seems to be the optimal, although in some cases, shorter 2 min rest intervals seem sufficient. Research results clearly indicate the need for individualization in the selection of this PAP variable.

In summary, PAP has a positive effect on speed abilities which has been demonstrated in the majority of studies presented in this review. This has also been verified and confirmed by a meta-analysis of data from the presented studies (Table 2).

Table 2. The results of a meta-analysis for data related to the impact of PAP on speed abilities in soccer players.

Publication	Effect	(CI d.	CI u.)	p	Percent %
Garcia-Pinillos F. et al.	E	(1,74	28,17)	0,0062	8,64%
Nealer A.L. et al.	NE	(0,41	6,82)	0,4773	8,49%
Chatzopoulos D.E. et al.	WE	(1,00	6,61)	0,0500	14,84%
Alves J.V. et al.	E	(1,54	12,37)	0,0056	13,10%
Low D. et al.	E	(1,36	23,27)	0,0171	8,38%
Till K. & Cooke C.	NE	(0,37	5,32)	0,6156	9,26%
Nickerson B. et al.	E	(1,72	15,98)	0,0035	11,98%
Dello Iacono A. & Seitz L.B.	E	(1,47	24,55)	0,0127	8,49%
Vanderka M.et al.	NE	(0,50	2,70)	0,7355	16,83%
Summary	E	(1,88	4,77)	0,0000	100,00%



Effect: WE (weak positive effect); E (positive effect); NE (negative effect).

THE IMPACT OF PAP ON EXPLOSIVE STRENGTH IN SOCCER PLAYERS

The second motor ability considered in the review of the PAP effect in soccer players includes explosive strength. To determine the changes in this ability, polymeric exercises, such as the CMJ test, were used. Jumping ability is an extremely valuable in soccer, especially in duels in the penalty area. This ability is equally significant for both defenders and attackers. Many goals are scored by striking the ball with a jumping header.

Frequent et al. (2011) examined the correlations between the activation of knee extensors and jumping ability of soccer players. During the study they established that the PAP effect (electrically evoked) in the knee extensors substantially impacted vertical jump and sprint performance in professional soccer players, similar to that observed previously in other elite athletes.

Another study presented by (Stage et al. 2011) verified whether depth jumps used during a soccer warm-up would evoke the PAP effect at a level that significantly enhanced vertical jump performance. The study examined 17 youth female soccer players who participated in 5 training sessions separated by 48 hours of recovery. Each session involved a warm-up on a cycle ergometer, 3 baselines vertical CMJs followed by 0, 3, 6, 9 and 12 depth jumps. The research protocol used a 10-min recovery period. The researchers assumed that the vertical jump height and relative ground reaction force (rGRF) were dependent variables. However, they did not reveal any important interactions during testing and no significant changes were observed in rGRF. The research protocol used in the study, did not elicit the PAP effect in the athletes, causing a decrease in vertical jump performance. The authors concluded that the use of such a training protocol in the warm-up does not lead to the improvement in vertical jump performance of soccer players.

Garcia-Pinillos et al. (2014), evaluated the effects of a 12-week isometric and plyometric contrast training (CT) without additional external load on jumping ability, strength of ball kicking, and agility in youth soccer players. Before and after the 12-week training program, the researchers evaluated the effects of PAP on standing jump height, agility (Balsom Agility Test), running speed at 5, 10, 20 and 30 m and ball kicking force. The two-way analysis of variance (group and temporal) revealed improvements ($p < 0.001$) in the counter-movement jump (CMJ), in the agility test (BAT) and ball kicking force. The authors concluded that the use of adequate isometric-plyometric training in youth soccer players improves sport-specific abilities, such as agility, vertical jumping performance and ball kicking strength.

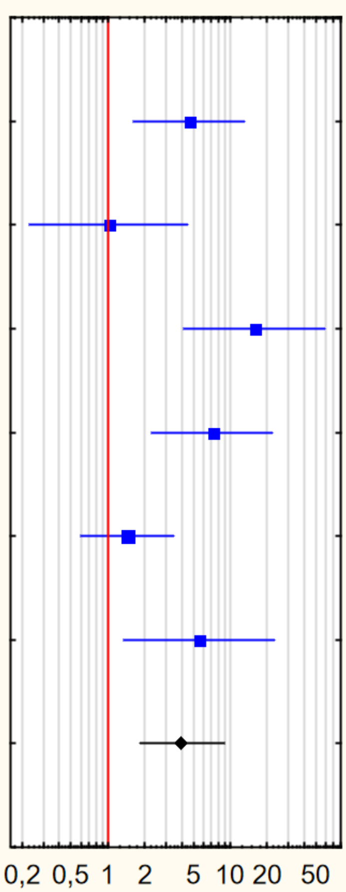
The team of Jameson and Mola (2013) evaluated the optimal recovery duration between muscle activation and performing an explosive, sport specific activity in soccer players (Mola 2013). Resistance exercises with a high load are performed in order to evoke the PAP effect in muscles. Twenty-two professional soccer players participated in the study and were divided into an experimental (n=11) and a control group (n=11). Both groups performed a standard warm up and baseline CMJ followed by a 10-min rest interval. The control group performed a CMJ at 15 s and 4th, 8th, 12th, 16th and 20th minute, whereas the experimental group performed 3 x 1RM squats, followed by the CMJ jump according to the same protocol. No significant differences were found between the experimental and control groups concerning peak power and jump height during the CMJ. The researchers observed an individual PAP profile for 6 participants: for 3 players, optimal recovery time was 4 min, for one - 12 min, and for the remaining two - 16 min, whereas for 5 players these profiles were impossible to be established. Therefore, individual "recovery windows" used in strength and power training should be determined for athletes before starting the general training programs for the entire team.

In a study published by Adriano (Titton et al., 2017) the researchers used 16 combinations of various variables to elicit the PAP effect in muscles that were expected to improve jumping performance in youth soccer players. Twenty-five young soccer players participated in a 5-step experiment. At first, maximal load (1RM) during the half squat was determined. The following 4 sessions involved combinations of half squats with the load of 40%, 60%, 80% and 100% using 4 different recovery durations between the sets of exercises (1, 3, 5 and 10 min). Each exercise was followed by a CMJ. Each combination of the load and recovery was separated by a 30-minute interval. The study found that a 1 min recovery had the highest effect on the improvement in jump height compared to 3, 5- and 10-min rest intervals. The worst results in the study were obtained after a 10-min rest interval. Therefore, it can be assumed that strength training composed of half-squats performed at 1 min rest intervals should be used to improve jumping performance in youth soccer players.

The aim of the study published by Alves et al. (2010) was to analyse the effects of complex and contrast training (CCT) on vertical jump and sprint performance (5 and 15 m), and agility in elite young Portuguese soccer players. Improvements in squat jump (SJ) height of 12.6% were registered in the first group and 9.6% in the second group. The authors concluded that the training protocol used in the study has a positive effect on explosive strength in youth soccer players.

In one of the recent publications by Rhibi et al. (2017) concerning the use of PAP effect in soccer, the authors evaluated acute effects of two types of warm-up protocols (plyometric and isometric) on jumping performance. Forty-five soccer players volunteered to participate in the study. They were randomly assigned to three groups: plyometric, isometric and control. The examinations were performed outdoors. During the first session, the researchers collected anthropometric data. The second session was organized 7 days later and began with a 10-minute warm-up composed of running and coordination exercises. Next, the athletes performed a set of dynamic exercises, such as lounges, squats and calf rise. After a 3 min rest interval, either isometric or plyometric exercises were administered. SJT and 5JT were performed using the plyometric platform. Improvements in the SJT and 5JT performances were observed in both experimental groups. It was concluded that the use of various warm-up protocols composed of isometric and plyometric exercises has a positive effect on jumping performance in soccer players.

Table 3. The results of meta-analysis for data on the impact of PAP on explosive strength in soccer players.



Publication	Effect	(CI d.	CI u.)	p	Percent %
Requena B. et al.	E	(1,63	13,17)	0,0041	18,45%
Stieg J.L. et al	NE	(0,23	4,53)	0,9784	13,94%
Garcia-Pinillos F. et al.	E	(4,24	60,31)	0,0000	15,48%
Mola J et al.	E	(2,28	22,67)	0,0008	17,32%
Titton A. & Franchini E.	NE	(0,60	3,52)	0,4065	20,25%
Rhibi F. et al.	E	(1,36	23,27)	0,0171	14,58%
Summary	E	(1,79	8,89)	0,0007	100,00%

Effect: WE (weak positive effect); E (positive effect); NE (negative effect).

The effectiveness of resistance exercises on speed and jumping abilities in soccer players was the focus of research by Tillin & Bishop (2009). The author examined the effects of both, dynamic exercises and isometric voluntary contractions (MVS) on players' sprint speed and jump height. The study protocol was planned in detail with the training loads individualized for all soccer players participating in the research. After completing the sprint test, the athletes performed 3 vertical CMJs on the Newtest Powertimer 1.0 Testing System. Analysis of the results did not reveal a significant PAP effect on jumping performance following the training protocol with dynamic and isometric exercises. The effectiveness of PAP in regard to sprint and jumping performance varied significantly between the tested athletes. The authors concluded that PAP protocols should be strictly individualized to maximize training effectiveness.

Similarly, to speed abilities, PAP based exercise protocols can improve explosive strength, including jumping abilities in soccer players. The effectiveness depends on the appropriate choice of several variables, which include type of exercise, its volume and intensity and the rest interval between the activating activity and the speed or explosive strength task. For youth and beginner athletes the intensity of activating exercises should be lower (50-60%1RM), not to induce muscle damage and post exercise pain (DOMS). In younger athletes a shorter recovery interval (1-2 min), is more effective in eliciting the PAP effect. Longer rest interval (8-10 min) is more effective with experienced athletes, who use greater loads in the conditioning exercises (80-90%1RM). The authors of most research projects related to PAP and explosive strength emphasize the need to individualize the intensity of the activating exercise and the length of the rest interval. A combination of isometric-plyometric exercises seems very effective in eliciting PAP during explosive strength activities in soccer players.

In summary, positive effects of PAP on explosive strength abilities have been demonstrated in the majority of presented research papers. This has been verified and confirmed by the meta-analysis of data considered in this paper (Table 3).

CONCLUSION

In conclusion, it can be stated that the use of complex training and the PAP effect seems very effective in improving sprint speed and explosive strength in soccer players of all ages and sports levels. Most studies on PAP in soccer indicate the necessity to evaluate individual rest intervals between the conditioning exercise and the explosive activity as particular players respond differently to the same load. This ensures the optimal post-activation potentiation induced by the resistance exercise. Most previous studies indicate that, post-activation potentiation has a direct effect on sprint speed improvement in soccer players. This concerns especially starting speed, assuming that players subjected to the PAP intervention have adequate sports skills, and the training loads applied in the conditioning exercises are high or very high (80-90%1RM). Most studies documented at least minor improvements in jumping test results following PAP exercise protocols. In addition, there is a lack of studies describing the PAP phenomenon using the internal structure of the movement (Krol and Golas 2017, Golas 2018), different time of tension (Wilk et al. 2019a, Wilk et al. 2019b) and training using blood flow restriction (Wilk et al. 2018), which should constitute future research directions. The studies presented in this review have also demonstrated the effectiveness of PAP in warm-up protocols on explosive strength, agility and jumping performance. It should be emphasized that few reports have analysed the PAP effect in soccer, especially in regard to female soccer players (2 studies), which implicates future directions of investigations.

AUTHORS CONTRIBUTIONS

Katarzyna Pajerska. Collected data, conceived and designed the analysis, performed the analysis, wrote the paper. Tomasz Zajac. Collected data, conceived and designed the analysis, performed the analysis. Aleksandra Mostowik. Collected data, wrote the paper. Sylwia Mrzyglod. Collected data, performed the analysis. Artur Goals. Collected data, conceived and designed the analysis, performed the analysis.

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