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Effect of Post-Activation Potentiation on Sprint Performance after Combined Electromyostimulation and Back Squats

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Abstract: Post-activation potentiation (PAP) is a phenomenon which can improve force performance executed after a previous conditioning activity. PAP is usually evoked through heavy resistance, but many new methods are being suggested that acutely improve performance in post-activation potentiation protocols. The purpose of this study was to examine the effect of simultaneous application of Smith machine back squats (BS) with electromyostimulation (EMS) on sprint performance. Sixteen male (age = 22.9 ± 2.3 years, body mass = 79.9 ± 13.8 kg, BS one-repetition maximum (1 RM) = 120.5 ± 17.3) amateur football and rugby players volunteered for this study. Participants randomly performed PAP protocols (CON = no load, BS = 3 × 85% of 1 RM BS, EMS = 3 × weightless squat with electric current and BS + EMS = 3 × 85% 1 RM BS with electric current) on four different days with at least 48 h intervals. Participants rested passively for 7 min after preloads and performed the 30 m sprint test. Sprint times for 10 and 30 m were recorded for each condition. As a result, no significant difference was found in the 10 m (p = 0.13) and 30 m (p = 0.10) sprint performance between the preload protocols. The effect size was found to be trivial (ηp^2: 0.13 for 10 m; ηp^2: 0.11 for 30 m). In individual results, the 10 m sprint performance of five participants and 30 m sprint performance of two participants decreased in BS, EMS, or BS + EMS conditions compared with CON. No PAP effect in other participants was observed. In conclusion, preloads did not affect 10 m and 30 m sprint performance of football and rugby players. It can be said that the applied PAP protocols or physical exertion alone may cause fatigue in some individuals.

Keywords: PAP; preconditioning; warm-up; individual response; explosive force

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1. Introduction

Sprinting and explosive force are principal performance determinants in team sports. Coaches try many methods to develop these skills and one of these methods is the phenomenon of post-activation potentiation (PAP). PAP is defined as an acute increase in performance after a moderate or severe muscle contraction [1]. The contractile history of a muscle group can positively or negatively affect the performance of that muscle group. Although the physiological underpinnings of PAP are not completely clarified, three theories have been put forward which may explain what underlies the increase in performance of athletes. The first is the increase in the phosphorylation of myosin regulatory light chain molecules, the second is the increase in the involvement of large motor units producing high force, and the third is the decrease in the angle of pennation in the muscles [1,2]. In a study conducted on amateur team players, 10 × 1 repetitions of 90% 1 repetition maximum (RM) back squat were performed and after 5 min of rest, 10 m and 30 m sprint performance was increased [3]. In another study, 3 × 90% 1 RM back squats and power cleans were performed as a preload. After 7 min of rest, 20 m sprint performance significantly increased in both applications [4]. Many preloading methods are applied for the PAP effect. Although heavy resistance exercises are mostly performed, isometric contractions, plyometric jumps, weight vests, and electromyostimulation (EMS) applications have also been investigated [5–7].

EMS is an application that provides induces muscular contraction by stimulating motor neurons and intramuscular axonal branches in skeletal muscles from the skin surface with electrical stimuli [8]. It has been known for many years that muscles can be stimulated by passing an electric current through the muscle or the peripheral nerves. Many studies examining the chronic effects of EMS applications have shown an increase in strength or power [9–11]. However, the number of studies investigating the acute effects of EMS is scarce. Requena et al. [12] examined the twitch potentiation of the knee extensor muscles after EMS and voluntary isometric contractions. As a result, an improvement in twitch potentiation occurred immediately after the voluntary contractions at the first and third minutes, whereas a significant increase was observed in the EMS measurements at the first, third, fifth and tenth minutes. In another study, two different contractions were performed to the quadriceps muscle group by leg extension (6 × 85% 1 RM) and EMS (6 × 120 Hz, 4 s contraction, 4 s rest) methods. The vertical jump heights obtained at 30 s and the first and third minutes after preloads increased significantly after both voluntary contractions and involuntary contractions created by EMS [5]. Although few studies have examined the acute effects of EMS, these studies suggest that EMS can be used for PAP [5,12]. It is generally difficult to activate high-threshold motor units with voluntary contractions, but this is possible with EMS. Large motor units have lower axon resistance compared with small motor units. For this reason, large motor units are more easily depolarized by externally applied electrical stimuli [13,14]. The size principle in normal motor unit number during voluntary contractions differs during EMS [15–17]. According to this size principle, progress in motor unit involvement during voluntary muscle contractions occurs from small units (slow twitch, small diameter) to large units (fast twitch, large diameter) [15,16,18]. In EMS, on the other hand, since there is no order in motor unit participation, large motor units can also be involved in the work simultaneously [19]. This may explain the mechanism underlying the PAP effect that occurs with EMS. In this regard, using only EMS can be considered as an alternative method to reduce the risk of injury that may occur in resistance exercises using large external loads [9]. The use of EMS to create the PAP effect during the pre-competition warm-up phase can be used to reduce this risk, especially by athletes with a history of injury and at risk of injury. For these reasons, it seems sensible to use EMS for the PAP effect.

To the authors' knowledge, there are no other studies in the literature that investigate the effects of performing EMS alone or in combination with back squats on 10 or 30 m sprint performance. Therefore, the aim of this study is to activate high-threshold motor units, which are difficult to activate by voluntary contraction, by applying EMS concurrently with back squats, and to create a greater PAP effect by providing more intense contractions in the stimulated muscles. We hypothesized that combined application of Smith machine back squats and EMS would significantly improve 10 and 30 m sprint performance.

2. Materials and Methods

2.1. Design and Participants

This study was performed with a randomized and crossover design. Subjects participated in five test sessions spaced 48 h apart. All tests were performed at the same time of day to control the effects of the circadian rhythm. Anthropometric measurements, 1 RM Smith machine back squat, and EMS intensity were determined on the first day (familiarization). Then, a 30 m sprint test was performed as a familiarization test. On the other four experimental days, participants were randomly assigned to PAP protocols [control (CON), Smith machine back squat (BS), electromyostimulation (EMS), and Smith machine back squat + electromyostimulation (BS + EMS)]. After applying standard warm-up and PAP protocols, 7 min of passive rest was given, and a 30 m sprint test was performed (Figure 1).

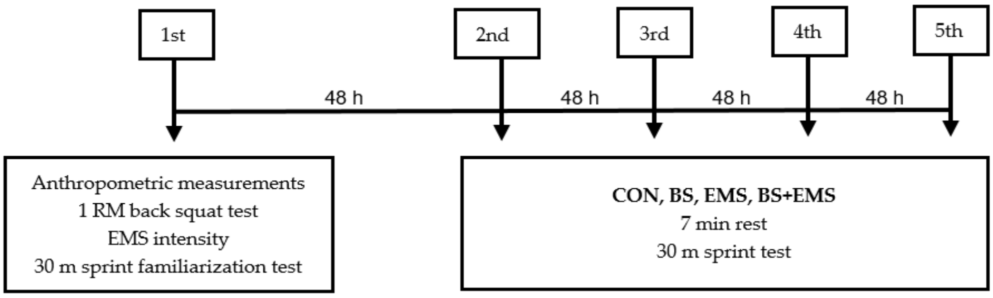

Figure 1. Experimental design. CON = control; BS = Smith machine back squat; EMS = electromyostimulation; BS + EMS = Smith machine back squat + electromyostimulation.

16 male (mean ± SD; age = 22.9 ± 2.3 years, body mass = 79.9 ± 13.8 kg, Smith machine back squat 1 RM = 120.5 ± 17.3 kg, relative strength = 1.5 ± 0.8 kg·kg^{-1}, training experience = 9.8 ± 3.6 years) amateur football and rugby players, who had been active athletes for at least 5 years but could not train for 5 months due to the COVID-19 pandemic restrictions, voluntarily participated in the research. The approval of the Ankara University Faculty of Medicine Human Research Ethics Committee was obtained for the study (decision no. = I3-155-20). Participants were not included in the study if they had any chronic disease, musculoskeletal injury, or required continuous medication. Before the tests, all participants signed an "Informed Consent Form" stating that they voluntarily participated in the study. The study was conducted according to the guidelines of the Declaration of Helsinki. Each athlete who agreed to participate in the study was informed of the content and risks of the study. All participants were advised not to engage in vigorous physical activity and not to consume alcohol and caffeine for the 24 h before the measurements.

2.2. Anthropometric Measurements

Participants' stature was measured with a 1 mm stadiometer (Seca 213, Hamburg, Germany), and body mass and body fat percentage were measured with a bioelectrical resistance device (Tanita Body Composition Analyzer MC-780MA, Tokyo, Japan).

2.3. Smith Machine Back Squat 1 Repetition Maximum Test

1RM back squat values were determined on a Smith machine (Esjim, Eskisehir, Turkey). Smith machine back squat depth was set at a knee joint angle of 85–90° (full extension = 180° knee angle) and this was also the depth that was used in the PAP protocols. After a 5 min walk, the participants completed the warm-up protocol by performing 8–10 repetitions of Smith machine back squats on an empty bar weighing 20 kg. Afterwards, the participants performed 3–5 repetitions at 60–80% of the estimated 1 RM weight and rested for 2 min. In the third stage, 90–95% of the estimated 1 RM weight was increased by an amount that enabled the exercise to be performed 2–3 times, and 4 min of rest was given. Finally, a 1 RM attempt was performed. The maximum lifted weight value was recorded. The 1 RM value was determined in 4–5 stages [20].

2.4. Electromyostimulation Application

Electromyostimulation was applied with a programmable 4-channel wireless EMS device (Compex SP 6.0, Geneva, Switzerland). One 5 × 10 cm and two 5 × 5 cm electrodes were used for each leg. Large electrodes were placed on the rectus femoris muscle at the level of the greater trochanter of the femur and the outer margin of the electrode was in line with the anterior superior iliac spine, and small electrodes were placed on the ending regions of the vastus medialis and vastus lateralis muscles 3 cm above the upper border of the patella. EMS stimuli were applied at the maximal intensity that the participants could tolerate, at a frequency of 100 Hz, and during the body mass or Smith machine back squat exercise during knee flexion and extension. To determine the current intensity, the electrodes were placed on the quadriceps muscle group while the participants were sitting on the chair, and the current was given at the lowest intensity and at a frequency of 100 Hz. While the participants were doing the body mass or Smith machine back squat movement, the current intensity was gradually increased and the maximum value at which the movement could be applied correctly was recorded.

2.5. 30 m Sprint Test

The 30 m sprint test was measured with a photocell timing system (Fusion Sport Smartspeed PRO, Brisbane, QLD, Australia). Three photocell gates were placed at the starting point, and at 10 m and 30 m points along a straight line. Photocell doors were set at a height of 1 m above ground level and the athletes started the test 0.5 m behind the door. The 30 m sprint test was performed once per session. The 10 m and 30 m sprint values were recorded. Before and during the test, the participants were verbally motivated.

2.6. Standard Warm-Up Protocol

Participants ran at a constant speed of 6.5 km/h on the treadmill for 5 min. Then, they applied dynamic stretching movements for 2 min. Participants were warned not to do static stretching, jumping, and short sprint runs.

2.7. PAP Protocols

No preload was applied in the CON protocol. In the BS protocol, 3 repetitions, separated by 30 s rest, were performed at 85% of 1 RM Smith machine back squat. In the EMS protocol, while electric current was given to the quadriceps muscle group, a body mass squat exercise was performed for 3 repetitions (30 s rest between repetitions) simultaneously, without additional resistance. In the BS + EMS protocol, 3 repetitions (30 s rest between repetitions) of Smith machine back squats were performed at 85% of 1 RM, while electric current was applied to the quadriceps muscle group with the EMS device concurrently.

2.8. Statistical Analyses

The number of required participants was determined with the G*Power 3.1 software program (Heinrich Heine University Dusseldorf, Dusseldorf, Germany). IBM SPSS 22.0 (IBM Corp., Armonk, New York, USA) and Microsoft Excel 2016 programs (Microsoft Corp., Seattle, WA, USA) were used in the analysis of the data. A Shapiro–Wilk test was used to confirm normal distribution. The 10 m and 30 m sprint performances were evaluated using one-way analysis of variance (ANOVA) in repeated measurements. The sphericity assumption was determined by the Mauchly test. In cases where the sphericity assumption was not met, the Greenhouse–Geisser correction was applied if Epsilon < 0.75, and the Huynh–Feldt correction was applied if Epsilon > 0.75. The significance level (p) was accepted as 0.05 in all analyses. The effect size was evaluated with partial eta square (ηp^2), defined as trivial (<0.10), moderate (0.25–0.39), or large ($\geq$0.40) [21]. Ten-meter and thirty-meter sprint performances after preloads were also evaluated at the individual level, as the PAP effect differs individually as positive responders, negative responders, inconsistent responders, and non-responders [22]. Thus, the Smallest Real Difference (SRD) values for the 95% confidence interval were determined using the formula as follows: "SRD: $1.96\sqrt{2} \times$ standard error of measurements (SEM)" [23,24].

3. Results

Table 1 shows 10 and 30 m sprint performances. According to the results of one-way ANOVA, there was no statistically significant difference between PAP protocols ($p > 0.05$).

The effect size (F = 2.40, $\eta p^2 = 0.13$ for 10 m, F = 1.94, $\eta p^2 = 0.11$ for 30 m) was trivial (Table 2). In other words, PAP protocols did not improve 10 m and 30 m sprint performance.

Table 1. 10 and 30 m sprint values after PAP protocols (n = 16).

	CON	BS	EMS	BS + EMS
Distance (m)	**Mean ± SD (s)**			
10	1.96 ± 0.07	1.98 ± 0.08	2.00 ± 0.07	2.00 ± 0.10
30	4.67 ± 0.22	4.65 ± 0.22	4.70 ± 0.22	4.70 ± 0.26

CON = control; BS = Smith machine back squat; EMS = electromyostimulation; BS + EMS = Smith machine back squat + electromyostimülation; SD = standard deviation.

Table 2. One-way ANOVA analysis of 10 and 30 m sprint values after PAP protocols (n = 16).

Distance (m)	F	p	ηp^2
10	2.40	0.10	0.13
30	1.94	0.13	0.11

F = F value, p = significance level; ηp^2 = partial eta square.

Since there were differences in the effect of PAP at the individual level, the effect of PAP on sprint performance was also evaluated individually. The individual sprint values are shown in Table 3. The SRD values obtained from the 10 m sprint test were calculated as 0.14 for CON-BS, 0.08 for CON-EMS, and 0.10 for CON-BS + EMS. According to the results, only EMS performance decreased in the 2nd, 12th, and 14th participants, both EMS, and BS + EMS in the 6th participant, and 10 m sprint performance decreased in the 10th participant after only BS (Figure 2).

Table 3. Participants' individual 10 m and 30 m sprint performance values after PAP protocols.

	10 m (s)				**30 m (s)**			
	CON	**BS**	**EMS**	**BS + EMS**	**CON**	**BS**	**EMS**	**BS + EMS**
1	1.94	1.93	1.98	1.94	4.60	4.61	4.72	4.59
2	1.94	1.88	2.06	2.03	4.66	4.69	4.92	4.85
3	1.97	1.96	1.98	1.98	4.77	4.61	4.62	4.65
4	2.00	2.02	2.04	2.02	4,72	4.62	4.74	4.76
5	2.06	2.07	2.07	2.11	4.79	4.77	4.77	4.91
6	2.01	2.09	2.12	2.21	5.26	5.20	5.15	5.39
7	1.99	2.09	2.02	1.99	4.65	4.74	4.68	4.61
8	1.98	2.00	1.95	2.00	4.56	4.50	4.52	4.54
9	1.95	1.85	2.03	1.88	4.52	4.39	4.61	4.44
10	1.82	2.05	1.85	1.84	4.42	4.52	4.40	4.43
11	1.98	1.95	2.01	1.99	4.67	4.52	4.77	4.74
12	1.93	1.97	2.02	2.01	4.62	4.78	4.79	4.81
13	1.86	1.81	1.86	1.83	4.30	4.21	4.26	4.23
14	1.89	1.95	1.98	1.97	4.50	4.71	4.65	4.62
15	2.05	2.03	2.04	2.03	4.80	4.68	4.69	4.71
16	2.09	2.07	2.14	2.18	4.98	4.91	5.06	5.01

CON = control; BS = Smith machine back squat; EMS = electromyostimulation; BS + EMS = Smith machine back squat + electromyostimulation.

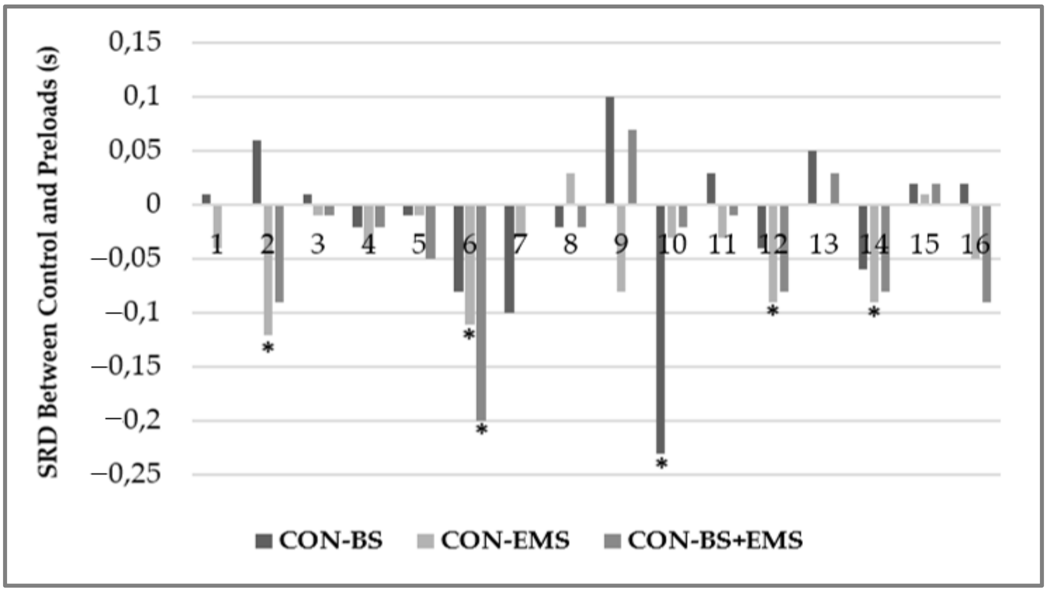

Figure 2. Individual performance changes compared with the control for each PAP protocol for the 10 m sprint. CON = control; BS = Smith machine back squat; EMS = electromyostimulation; BS + EMS = Smith machine back squat + electromyostimulation. *: Negative PAP effect (decreased sprint performance); unmarked values = no PAP effect; note = missing bars indicate the same preload and control times.

The SRD values obtained from the 30 m sprint test were determined as 0.22 for CON-BS, 0.22 for CON-EMS, and 0.17 for CON-BS + EMS. According to the results, the 2nd participant's 30 m sprint performance decreased after EMS and BS + EMS, and the 12th participant's only after BS + EMS (Figure 3).

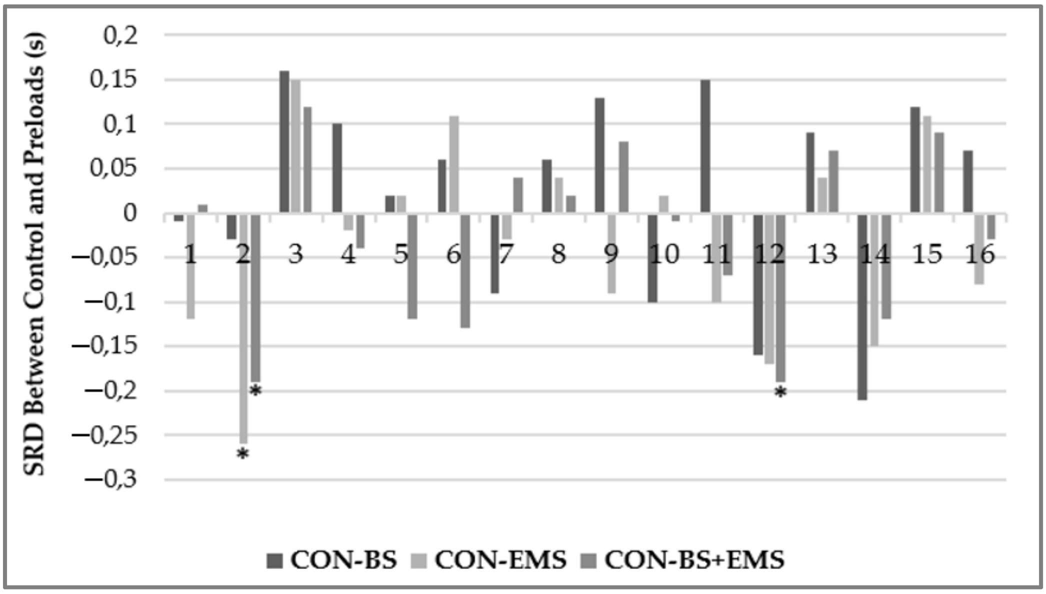

Figure 3. Individual performance changes compared with the control for each PAP protocol for the 30 m sprint. CON = control; BS = Smith machine back squat; EMS = electromyostimulation; BS + EMS = Smith machine back squat + electromyostimulation. *: Negative PAP effect (decreased sprint performance); unmarked values = no PAP effect; note = missing bars indicate the same preload and control times.

4. Discussion

The aim of this study was to examine the effect of simultaneous Smith machine back squats with EMS application on 10 m and 30 m sprint performance. Statistical analysis revealed no statistically significant differences between the preload protocols. In addition, according to the results at the individual level, the sprint performances of most of the participants did not change after the preloads, but a decrease in sprint performance was observed in some athletes.

Although there is no other study in the literature that applies combined pre-loading as we did, there are a few studies examining the effect of EMS as a PAP protocol on sport performance. However, these studies did not examine the effect of EMS on sprint performance. Kacoglu et al. [25] examined the acute effect of EMS on vertical jumps and isokinetic strength. In the 90° static squat position, 16 s (4 s contraction, 4 s rest) of EMS was performed on the quadriceps and calf muscle groups at different frequency levels (30 Hz and 100 Hz). Significant increases in vertical jump heights and 180 and 300°/s knee flexion isokinetic power performances were reported after 90 s [25]. In another study, EMS and leg extension, as PAP protocols, were compared. Vertical jump heights at 30 s and 1 and 3 min after preloads improved in both protocols [5]. The results of these studies contradict ours in terms of PAP effect. Fast twitch muscle fiber plays an important role at high concentric speeds [11]. It has been reported that small and large motor units are recruited simultaneously during EMS [19,26]. The fact that EMS applications can activate fast twitch fibers at a lower action potential threshold than voluntary contractions suggests that EMS can reveal the PAP effect. However, voluntary contractions were reported to be more effective than EMS [27–30]. Therefore, in the current study, although we aimed to obtain a strong PAP effect by using EMS contractions, which can easily activate high-threshold motor units together with voluntary contractions, performance improvements were not observed. Our participants could not train regularly due to the restrictions imposed during the COVID-19 pandemic. Since this causes a decrease in maximal strength levels, it can be speculated that the simultaneous application of two contraction methods in preloads may create excessive fatigue. In a meta-analysis by Seitz and Haff [31], male participants were classified as "strong" if the ratio of 1 RM back squat value to body mass was ≥1.75, or "weak" if they were <1.75. As a result, the effect size of PAP was determined as 0.41 in strong participants and 0.32 in weak participants [31]. In another meta-analysis, the effect size of PAP was reported as 0.81 in athletes, 0.29 in trained individuals, and 0.14 in untrained individuals [32]. When considering the average body mass (79.98 ± 13.37 kg) and 1 RM average value (120.5 ± 17.39 kg) of our participants (relative strength = 1.50), it is seen that they are classified as being in the "weak" category. Therefore, we can say that the PAP effect did not occur due to the weakness of our participants. Other studies with weak participant groups that found no PAP effect support our results [33,34]. More research on trained and "strong" participants is needed to reveal definitive results of simultaneous back squat preloading with EMS.

Studies [31,34–36] have reported that the duration of recovery times given after preload may affect the PAP response and those optimal resting times may depend on the strength level of individuals. It was stated that "strong" individuals achieved the greatest PAP effect at 5–7 min after preload, whereas "weak" individuals obtained maximum PAP response after at least 8 min of recovery [31]. Another study reported that "strong" individuals had the best PAP response at the sixth minute after the back squat, and the "weak" individuals reached the best PAP response at the ninth minute [34]. The fact that "strong" individuals showed the greatest PAP effect earlier can be explained by their faster metabolic and neuromuscular recovery capacity against fatigue after a severe preload [35,36]. From this point of view, it can be stated that the seven-minute rest period applied in our current study may be insufficient for the recovery of our "weak" participants. The fact that adequate rest time varies–depending on the type of preload, its intensity, the number of repetitions, individual differences of the participants, and the type of subsequent explosive force performance–complicates the determination of an optimal rest interval.

The current research was designed as an extension of previous studies, and the findings were also analyzed at the individual level. It is difficult to obtain a statistically significant "*p*" value since experimental studies on athletes are generally performed in a small number of sample groups. In addition, despite no statistically significant difference, the smallest (0.5–1%) changes can provide significant differences in performance. Therefore, in studies conducted with athletes, SRD values were used to detect the smallest change that could make a significant difference in real world settings [23,24]. According to individual results, five participants experienced a decrease in 10 m sprint performance after preloads, whereas only two participants experienced a decrease in 30 m sprint performance. None of the participants were observed to be individually positively affected by preloads. Till and Cooke [6], in their study, reported that although they did not observe a change in sprint performance after different preloads, individual differences emerged. Deadlift, tuck jumps, and isometric knee extension were applied as preloads, and it was observed that some participants' sprint performance increased by 4.6% after deadlifts and isometric knee extension, although the sprint performance of some participants decreased. In another study that showed similar results, no significant improvement was observed in the 10, 20, and 30 m sprint tests performed 4 min after the preloads, but large differences were observed among the participants. It was stated that although some participants experienced an increase or decrease in their performance, some did not [37]. The findings of studies examining the effect of PAP at the individual level are in line with the results of the current study. However, in addition to all other aforementioned moderating factors above, the lack of participants who showed a positive PAP effect in our study and the decrements in performance of some participants can be mainly attributed to the decrease in the fitness levels of individuals as a result of the inability to undertake team training for a long time due to the COVID-19 pandemic.

The current study is not without limitations. Results of our study may be affected by heavy preloads or insufficient recovery time. Further, many studies have reported that individuals' responses to PAP protocols may be affected by the variation in individuals' training status and strength levels [31,35–39] and our participants could not train for five months due to the COVID-19 restriction. Therefore, a more personalized approach is required to determine optimum preloads and rest times when planning PAP applications. The 48 h gaps given between test sessions might be insufficient, which, in turn, may have affected our results. Lastly, the sprint tests were carried out indoors but participants typically train and compete outdoors.

5. Conclusions

Findings from this study showed that simultaneous Smith machine back squats and EMS preloads applied to amateur football and rugby players did not increase 10 m and 30 m sprint performance. However, it should be taken into account that the participants were untrained due to the COVID-19 pandemic. Individual results showed that most of the participants did not respond to preloads, whereas some were negatively affected. Therefore, individual differences are important in PAP studies and a personalized approach is required.

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