

Research article

Effects of a Whole-Body Electrostimulation Program on Strength, Sprinting, Jumping, and Kicking Capacity in Elite Soccer Players

Andre Filipovic^{1,2}✉, Marijke Grau², Heinz Kleinöder¹, Philipp Zimmer², Wildor Hollmann² and Wilhelm Bloch²

¹Institute of Sport Science and Sport Informatics, German Sport University Cologne, Germany

²Institute of Molecular and Cellular Sport Medicine, German Sport University Cologne, Germany

Abstract

The aim of the present study was to investigate the effect of a 14-week dynamic Whole-Body Electrostimulation (WB-EMS) training program on muscular strength, soccer relevant sprint, jump and kicking velocity performance in elite soccer players during competitive season. Twenty-two field-players were assigned to 2 groups: WB-EMS group (EG, n = 12), jump-training group (TG, n = 10). The training programs were conducted twice a week concurrent to 6-7 soccer training sessions during the 2nd half of the season. Participants were tested before (baseline), during (wk-7) and after (wk-14). Blood serum samples for analyzing IGF-1 and CK were taken before each testing, 15-30min post and 24h post the training program. Our findings of the present study were that a 14-week in-season WB-EMS program significantly increased one-leg maximal strength (1RM) at the leg press machine (1.99 vs. 1.66 kg/kg, p = 0.001), and improved linear sprinting (5m: 1.01 vs. 1.04s, p=0.039), sprinting with direction changes (3.07 vs. 3.25s, p = 0.024), and vertical jumping performance (SJ: 38.8 vs. 35.9cm p = 0.021) as well as kicking velocity (1step: 93.8 vs. 83.9 km·h⁻¹, p < 0.001). The TG showed no changes in strength and performance. The EG revealed significantly increased CK levels 24h post training and yielded significantly higher CK levels compared to the TG. IGF-1 serum levels neither changed in the EG nor in the TG. The results give first hints that two sessions of a dynamic WB-EMS training in addition to 6-7 soccer sessions per week can be effective for significantly enhancing soccer relevant performance capacities in professional players during competitive season.

Key words: EMS, whole-body, strength training, direction changes, elite athletes, football

Introduction

The physical demands of soccer players changed over the last 10 years due to modern game philosophies and tactics. Especially, the distances covered in the higher intensities and the number of explosive actions such as accelerations, turns, and jumps have increased (Di Salvo et al., 2010; Mohr et al., 2003). Therefore, a player's sprint ability and the dynamic and explosiveness of his movements are some of the most crucial criteria in today's talent scouting.

The results of our previous meta-analysis of EMS methods reveal that EMS training can be an effective alternative to the traditional resistance training and/or power training for developing maximal strength, speed strength, sprinting and jumping performance in elite athletes (Filipovic et al., 2012). Several studies with elite

athletes revealed positive effects of EMS on performance (Babault et al., 2007; Billot et al., 2010; Brocherie et al., 2005; Maffiuletti et al., 2000; 2002; Pichon et al., 1995; Willoughby and Simpson, 1996). Despite an already high level of strength of elite athletes, several studies were able to verify high gains of >30% in the maximal strength of the lower body muscles (Babault et al., 2007; Kots and Chwilon, 1971; Willoughby and Simpson, 1996; 1998). Some studies were able to directly transfer the strength gain into an improved vertical jumping (Babault et al., 2007; Herrero et al., 2006; Kots and Chwilon, 1971; Maffiuletti et al., 2000; 2002; Pichon et al., 1995) and sprinting performance of up to -4,8% (Herrero et al., 2006; Kots and Chwilon, 1971) within 3-6 weeks (cf. Ferrando et al., 1998; Filipovic et al., 2012). Other studies showed no effects on sprinting performance (Babault et al., 2007; Billot et al., 2010). Previous investigations revealed that the combination of EMS training with specific jump training (Herrero et al., 2006; Martinez-Lopez et al., 2012; Maffiuletti et al., 2002) or high-performance training have positive effects on the strength transfer and thus enhancing motor abilities such as jumping or sprinting performance in elite athletes (Babault et al., 2007; Maffiuletti et al., 2000; Malatesta et al., 2003; Pichon et al., 1995).

All of these studies applied EMS only to defined muscles of the lower body with single electrodes. With the new generation of EMS-devices several muscle groups can be trained simultaneously through an electrode belt- and vest system (e.g., miha bodytec, Augsburg, Germany). In comparison to the local EMS method (see above) there is only little research about applying WB-EMS methods with trained athletes (Kreuzer et al., 2006; Speicher et al., 2009) and almost no data about implementing WB-EMS in the training routine of elite team athletes for systematically enhancing sport performance.

The documentation of the CK-level is a widely used parameter in high-performance sports to control training intensity and recovery. Intense physical exercise stresses muscle tissue, which elevates the level of the CK in the blood serum. Accordingly, the serum CK-level is used as an indicator for muscle damage. Extreme muscle stress and subsequent damage or several intense stimuli on consecutive days can cause a summation of CK values. In contrast to voluntary exercise, EMS artificially activates muscle contraction without resistance load. Studies investigating the stimulation intensity and the responds of creatine kinase to EMS have shown that the electrical stimulus can produce higher muscular stress and conse-

quently a higher degree of muscle fiber damage than voluntary stimulus (Boeckh-Behrens et al., 2006; Jubeau et al., 2008; Kreuzer et al., 2006; Steinacker, 1999). Jubeau et al. (2008) assume that this could be due to the different recruitment of motor units during EMS compared with voluntary contractions.

Although little is known about the underlying mechanisms, some authors speculate neural adaptations such as a preferential activation of the large motor units of the type-II fibers with EMS as the main factor for the increase in strength (Hortobagyi et al., 1999; Maffiuletti et al., 2000; 2002; Pichon et al., 1995; Willoughby and Simpson, 1996). Hortobagyi and Maffiuletti (2011) concluded that EMS-programs up to six weeks may induce alterations in muscle metabolism. However, the authors stated that the increase in MVC (maximum voluntary contraction) is not a result of overt muscle hypertrophy and more due changes in some elements of the nervous system. Studies which applied EMS for time periods longer than six weeks suggested that hypertrophy might occur in the late phase of such programs (cf. Hortobagyi and Maffiuletti, 2011; Gondin et al., 2005, 2011; Ruther et al., 1995). Anabolic hormones such as the human growth hormone (hgH) play a dominant role in the regulation of protein metabolism and can be an indicator for muscle growth and hypertrophy. Jubeau et al. (2008) investigated the acute effect of EMS on hgH. They observed a significant increase in hgH for the EMS-group compared to traditional strength training. However, the authors did not investigate the changes in muscle mass. IGF-1 is also an anabolic hormone that is part of a signaling network that is involved in exercise-induced remodeling processes in the muscle (Goldspink, 2005; Hameed et al., 2003). In adaptation to resistance training IGF-1 increases the protein synthesis in the muscle cells (Butterfield et al., 1997; Ferrando et al., 1998). Further, IGF-1 activates satellite cells to proliferate and differentiate and thus could modulate skeletal muscles (Adams and Hadad, 1996). Resistance exercise is a powerful stimulus for the endocrine system. Studies have shown that the hormonal response to resistance exercise depend on several factors including number of sets, repetitions, training intensity and volume and rest intervals (Crewther et al., 2006). Research studies dealing with the acute response to IGF-1 have shown that strength exercise can elevate circulating IGF-1 and free IGF-1 (Kraemer and Ratamess, 2005; Rahimi et al., 2010). In contrast, other studies have shown no changes in acute IGF-1 after resistance exercise (Kraemer and Ratamess, 2005). No studies have yet investigated the acute metabolic responses to WB-EMS in elite athletes.

To our knowledge this is the first field-practice study that systematically implements a WB-EMS program in training routine of elite soccer players over 14 weeks to increase performance and test the WB-EMS method on practicability in professional soccer. Little is known about the underlying mechanisms of EMS, e.g. no studies have yet investigated the acute metabolic responses to WB-EMS in elite athletes.

For these reasons the aim of this study was to implement a dynamic whole-body EMS program in the in-

season training routine of elite soccer players on the basis of our previous studies to investigate the effects on maximal strength, sprinting and jumping performance, and kicking capacity. A further objective of this study was to investigate the effects on hormonal (insulin-like-growth-factor-1) and enzymatic (creatine kinase) parameters in order to explain possible adaptation mechanisms such as hypertrophy.

Methods

Participants

Twenty-two professional male soccer players, competing in the 4th division of the German Soccer Federation (DFB), voluntarily participated in this study. To our knowledge this is the first study to implement WB-EMS in the training routine of elite soccer players. In accordance with the principles of players' preference intervention, only players who did not have a strong group preference were randomized into either the WB-EMS group (EG) or the Jump-Training group (TG). To cope with possible dropouts in the WB-EMS group the players were assigned into a larger intervention group (EG) and a smaller control-group (TG): WB-EMS group (EG, $n = 12$; age 24.9 ± 3.6 years; height 1.84 ± 0.05 m; mass 80.6 ± 9.2 kg), control-group (TG, $n = 10$; age 26.4 ± 3.2 years; height 1.82 ± 0.07 m; mass 78.3 ± 9.3 kg). All players were professional soccer players and performed 6-7 training sessions per week and competed once a week in the championships. The standard training sessions lasting 70-90min including technical skill activities, offensive and defensive tactics, athletic components with various intensities, small sided game plays and 20-30min of continuous play. The playtime in championship- or friendly matches of the test persons were recorded during the study period (Table 1). The players were asked to maintain their usual food intake and hydration. During the study no additional strength training for the lower body was allowed. The study was conducted in the second half of the season from January until May. All players had at least five years of experience in systematic strength training. During the first half of the season strength training sessions were part of their daily soccer training routine minimum once a week. None of the players had trained with EMS before. All players were informed about the procedures and risks of the study and written informed consent was obtained. All experimental procedures performed were approved by the Ethic Committee of Human Research of the German Sport University Cologne.

Table 1. Playtime (minutes) in EMS-Group (EG) and Jump-Training-Group (TG) during the 14-week investigation period. Playtime was documented from week 0 until week 7 (Baseline - wk-6) and from week 7 until posttest in week 14 (wk-7 - wk-14). Values are presented in means (\pm SD).

	wk0-wk6	wk7-wk14
EG	561.9 (170.2)	879.3 (701.4)
TG	623.9 (115.1)	640.0 (610.6)

Experimental design

The study was designed as a randomized training study including a jump training group with simultaneous EMS

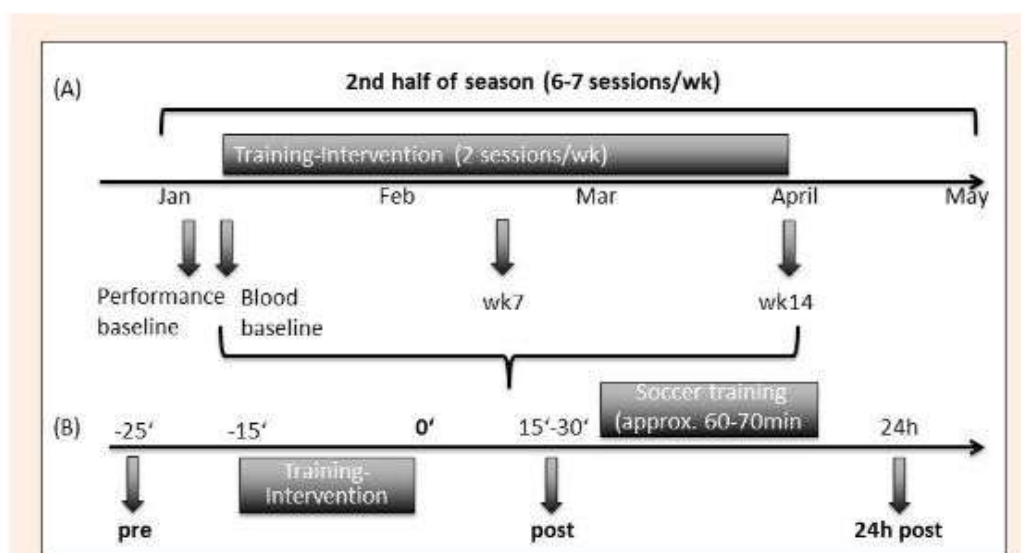


Figure 1. Timeline of performance testing and blood samples during the study in the 2nd half of the season (A). Timeline of blood samples collection at baseline, wk 7, and wk 14. At each testing samples were taken before (pre), after 15-30min (post), and 24h (24h post) after the training interventions (B).

(EG) and a jump training group without EMS (TG) as control group in order to investigate the effects of the WB-EMS stimulus on maximal strength and performance and exclude the possible effects of the squat jumps. The study was conducted during the second half of the competitive season. The training interventions were conducted twice per week in addition to 6-7 soccer training sessions and a match on the weekend. Performance was assessed before (baseline) after 7 weeks (wk7), and after 14 weeks (wk14) (Figure 1). All performance diagnostic tests were performed on Tuesday mornings in a standardized order as listed below. The 10 min standardized warm-up included dynamic movement preparations and static stretching. At the end of each warm-up followed by short movement activation phase the players performed three increased runs over 30m and three all-out sprints over 10m. No static stretching was allowed after warm-ups. The sprint tests and kicking tests were performed on an artificial ground (POLYTAN, FIFA norm 1 star). Vertical jump tests and strength tests were performed indoor in the club gym.

Testing procedures

Anthropometric parameters

Before each testing we documented the players' age (years), body height (cm), body weight (kg) (Table 1).

Linear sprint and sprint with direction changes

First, the players performed three linear sprints over 30m and then four soccer relevant sprints with direction changes over 15m according to Rehhagel (2011). The sprints with direction changes included a 1m sidestep after start, followed by a 10m linear sprint and a 5m sprint after a direction change of 45 degrees. To standardize the direction change the players had to hit two marks on the ground, one with each foot. The players performed two sprints from each side. Between the sprints the players rested for 120 s. Sprint time was measured with double

infrared photoelectric barriers with radio transmitter (DLS/F03, Sportronic, Leutenbach-Nellmersbach, Germany) positioned 1m from the ground. The players started the sprints from a standing position - 50cm for linear and 10cm for sprint with direction changes - behind the first photoelectric barrier. The fastest of the three respectively four trials was used for statistical analysis.

Kicking velocity

The players performed three shots from a distance of 6m with no run up (one step before kicking) and three shots with run up (3 steps before kicking) into a 100x80cm soccer goal by using the dominant leg (cf. Billot et al., 2010). An official FIFA match soccer ball (size 5, 440g) by JAKO with a pressure of 11.5psi was used (cf. Billot et al., 2010). Pressure was checked before each testing session. Ball speed was measured with "Speed TracX Sportradar" (10,525GHz). The radar device was positioned 40cm from the ground directly behind the net of the soccer goal. The fastest out of three trials was used for statistical analysis.

Vertical jump

The vertical jump height was measured with an "OptoJump" (Microgate, Bozen, Italy). The "OptoJump" device measures the jump height by measuring the flight time with the help of infrared photoelectric barriers. The players performed three trials of each vertical jump variation including one test jump. First, the players performed three vertical jumps starting from a static squatted position with knees 90 degrees (SJ) without any preliminary movement. For countermovement jump (CMJ) the players started from a standing position squatting down to a knee angle of approximately 90 degrees in order to build up momentum and then explosively jump as high as possible. The highest jump of the 3 trials per jump type was used for analysis. The drop jump (DJ) was performed from a box (38cm). Therefore, the players stepped respectively

jumped down from the box and then tried to jump as high as possible. The players were told to aim a contact time on the ground below 200ms. The players were instructed to keep their hands on the hips throughout all jump tasks. The highest relation (DJindex) between jump height and shortest contact time out of the three trials (jump height [cm]*10/contact time [ms]) was used for statistical analysis.

Maximal muscular strength

Tests were performed on a leg press machine (NORSK, Sequenztraining-system, Cologne, Germany). The players were positioned horizontal on the sledge with the hip and knee angle under 90°. The maximal strength of each leg was measured by the one-repetition-maximum (1RM) according to Beachle (1994). The players performed two series with 10 dynamic repetitions with submaximal weight for warm-up. To determine the 1RM, the players were allowed to use both legs to get in starting position with legs fully extended (180°). For testing, the players performed maximal repetitions with one leg (ROM knee angle 180°-90°, 2s/2s). If a player mastered more than six repetitions, a load of 10kg was added to the sledge for the next set after allowing a recovery interval of about three min.

Bloodparameters - CK and IGF-1

In each testing (baseline, wk7, wk14) blood samples were withdrawn before (pre), 15-30min after (post) and 24h after the interventions (24h post) (Figure 1). The players were told to maintain a seated position after the interventions for 15 min till the first blood samples were collected. Blood samples were stored - 80°C and were analysed after completing the study. Creatine kinase (CK) and the IGF-1 were analysed by Enzyme-linked Immunosorbent Assay (ELISA)-method according to the manufacture instructions (R&D Systems, Minneapolis, USA). All blood samples were taken on Thursdays (pre and post) between 10:00h and 12:00h before the soccer training session and on Fridays at the same time (24h post). The players' nutrition on the test days was recorded and the players were instructed to maintain the usual nutrition. No nutrition supplements were allowed during the study period.

Experimental training protocol

WB-EMS training was conducted on Mondays and Thursdays in order to obtain a rest interval of 48 hours between the two sessions and the championship game on Saturdays. The WB-EMS Training was conducted with a whole body-EMS-system by "miha bodytec" (Augsburg, Germany). WB-EMS was applied with an electrode vest to the upper body including the chest (m. pectoralis major and minor), upper back and lower back (m. latissimus, m. trapezius, m. erector spinae, m. iliolumbales), and abdominals (m. rectus abdominis) and with a belt system to the lower body including the muscles of the glutes (m. gluteus maximus and medius), thighs and hamstrings (m. rectus femoris, m. vastus medialis and lateralis, m.

biceps femoris, m. semitendinosus, m. semimembranosus, m. gracilis) and calves (m. gastrocnemius, m. soleus). The electrode belt for the thighs was positioned between hip and the knee joint space. For the calves, the belts were placed around the thickest part of the calves. The players started with a 2-3 min warm-up with easy movement preparations and jumps at a light to moderate stimulation intensity. The players were told to slowly increase the intensity every few impulses. The training started when the players reached the defined training intensity (see below). The EG performed 3x10 maximal squat jumps with a set pause of 60s (no currents) per session. Biphasic rectangular wave pulsed currents (80Hz) were used with an impulse width of 350µs. Every impulse for a single jump lasted for 4s (ROM: 2s eccentric from standing position to a knee angle of 90° - 1s isometric - 0.1s explosive concentric - 1s landing and stabilisation) followed by a rest period of 10s (duty cycle approx. 28%).

The stimulation intensity was determined and set separately for each muscle group by using a Borg-scale (6-20, [20-100%]). For the first two sessions the participants started with a moderate to sub-maximal intensity (13-15, [50-60%]). The stimulation intensity was then constantly increased individually every week. The players were told to maintain a high stimulation intensity (Borg-Scale 18-19, [80-90%]) that still assures a clean dynamic jump movement.

The TG performed the same amount of jumps with identical interval and conduction twice per week on similar days without EMS in addition to the 6-7 soccer specific training sessions per week.

All testing and training sessions were supervised and monitored by a strength and conditioning specialist.

Statistical analysis

The Kolmogorov-Smirnov test of the normality of distribution was conducted before the analysis. All parameters were normally distributed. Potential baseline differences between treatment groups were investigated using the student t-test for independent samples. Assumption of homogenous variances was tested using Levene test. In case of inhomogeneous variances Welch-test was used. To determine the effect of the training interventions a separate 3x2 (time*group) mixed ANOVAs with repeated measures were conducted. ANOVA assumption of homogenous variances was tested using Mauchly-test of Sphericity. If a violation of Mauchly's test was observed Greenhouse-Geisser correction was used. Partial eta-square (η^2_p) values are reported as effect size estimates. If 3x2 mixed ANOVA revealed a significant time*point*treatment or time*group interaction effect on any variable, this effect was further investigated carrying out Bonferroni corrected post hoc pairwise comparison. To detect correlations among pairs of variables Pearson product-moment correlation (one-tailed) was used. For all inferential statistical analyses, significance was defined as p-value less than 0.05. All descriptive and inferential statistical analyses were conducted using SPSS 22® (IBM®, Armonk, NY, USA).

Results

Effects on performance parameters

Group Comparisons: At the baseline test the TG showed a significant ($p < 0.05$) lower sprint time for linear sprint over 10m, and a higher kicking velocity with 1step run-up than the EG. After 14 weeks, the EG showed a significant ($p < 0.05$) higher 1RM at the leg press than the TG at wk7 ($p < 0.05$) and at wk14 ($p < 0.05$).

Anthropometric changes: We observed no changes in body weight and height in both groups during the study period.

One-Repetition-Maximum (1RM) legpress machine: The 3x2 mixed ANOVA on 1RM revealed a significant main effect of within-subjects factor time ($F = 9.481, d = 16, p = .002, \eta^2_p = 0.542$), and a significant time*group effect ($F = 8.169, d = 16, p = 0.004, \eta^2_p = 0.505$). Significant interaction effect on relative 1RM was further analyzed through post hoc comparisons. We observed significant increases for the EMS group (EG) in the maximal strength (1RM) at wk7 ($p < 0.01$) and wk14 ($p < 0.01$) compared to the baseline. The TG showed no changes in the maximal strength (Figure 2).

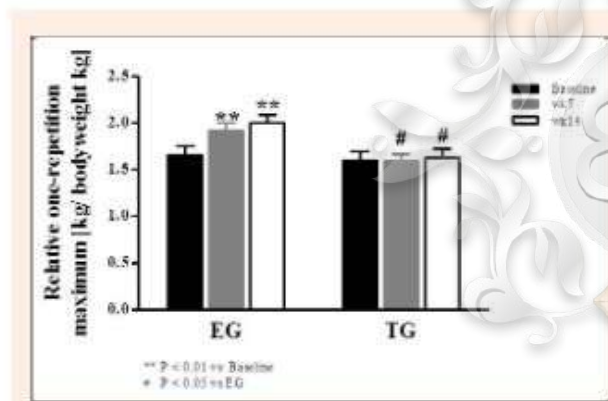


Figure 2. Relative maximal strength (1RM) at the leg press machine (one-legged) in EMS-Group (EG) and Jump-Training-Group (TG) measured before (baseline) after wk 7, and after wk 14. Values are presented in means ± SD, and significant differences at $p < 0.05$ (*) and $p < 0.01$ (**).

Vertical jump: We observed a significant main effect of within-subjects factor time for SJ ($F = 11.268, d = 17, p = 0.001, \eta^2_p = 0.57$), CMJ ($F = 9.625, d = 17, p = 0.002, \eta^2_p = 0.531$), DJindex ($F = 10.427, d = 17, p = 0.001, \eta^2_p = 0.551$) and a significant time*group effect for squat jump ($F = 6.104, d = 17, p = 0.01, \eta^2_p = 0.418$). The EG showed significant increases in SJ ($p < 0.05$), CMJ ($p < 0.05$) and DJindex ($p < 0.01$) at wk14 ($p < 0.05$). The TG showed no significant changes in SJ, CMJ, and DJindex compared to baseline (Figure 3).

Linear sprint: Concerning sprint performance we documented a significant time*group effect only for 5m ($F = 3.962, d = 17, p = 0.039, \eta^2_p = 0.318$). For 10m the analysis showed a non-significant time*group effect ($F = 3.52, d = 17, p = 0.53, \eta^2_p = 0.293$). We observed an improvement in the short sprint time for EG only over 5m ($p < 0.05$). The 10m sprint times improved till wk7 but

remained insignificant ($p = 0.53$) compared to baseline. The 20m, and 30m sprint times remained unchanged during the study. The linear sprint times for TG showed no significant changes in all measuring points for the entire study period (Figure 4).

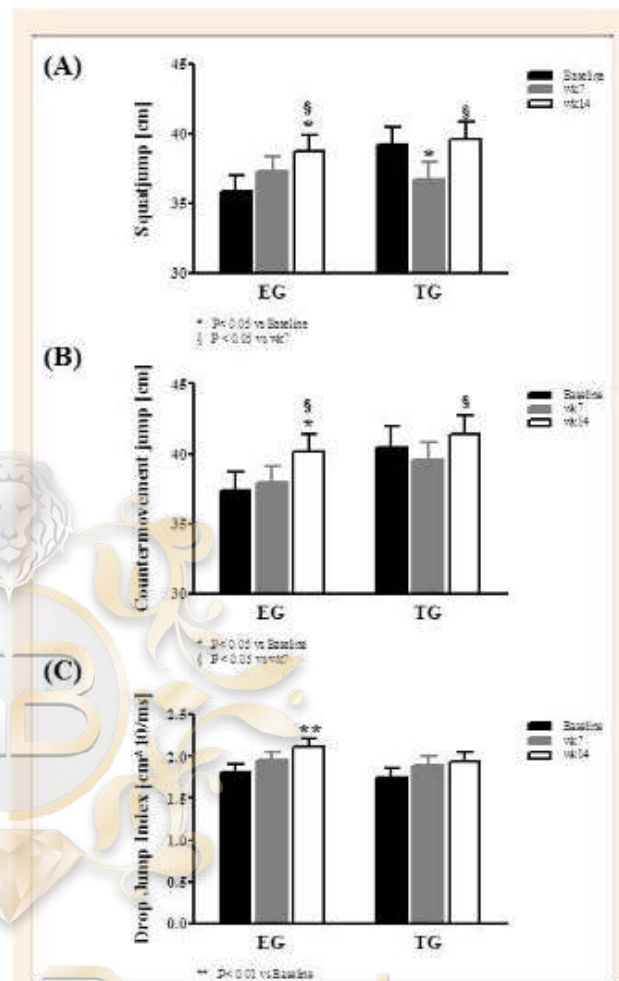


Figure 3. Squat Jump (A), Counter-Movement-Jump (B), and Drop-Jump Index (C) in EMS-Group (EG) and Jump-Training-Group (TG) measured before (baseline) after wk 7 and after wk 14. Values are presented in means ± SD, and significant differences at $p < 0.05$ (*) and $p < 0.01$ (**).

Sprint with direction changes: We showed a significant main effect of within-subjects factor time ($F = 6.169, d = 16, p = 0.01, \eta^2_p = 0.435$). The post-hoc analysis showed an improvement for EG at wk7 ($p < 0.05$), and wk14 ($p < 0.05$) compared to baseline. Sprint performance remained unchanged for TG (Figure 5).

Kicking capacity: The ANOVA revealed for both kicking variations significant main effects of within-subjects factor time (1-step: $F = 15.212, d = 15, p < 0.001, \eta^2_p = 0.67$; 3-step: $F = 5.378, d = 15, p = 0.017, \eta^2_p = 0.67$), and a significant time*group effect for 1-step ($F = 5.378, p = 0.017, \eta^2_p = 0.418$). For kicking performance, we observed for the EG a significant increase in ball speed with 1 step and 3 steps run-up at wk14 (1step, $p < 0.01$; 3step, $p < 0.05$). We observed no change in kicking performance for TG (Figure 6).

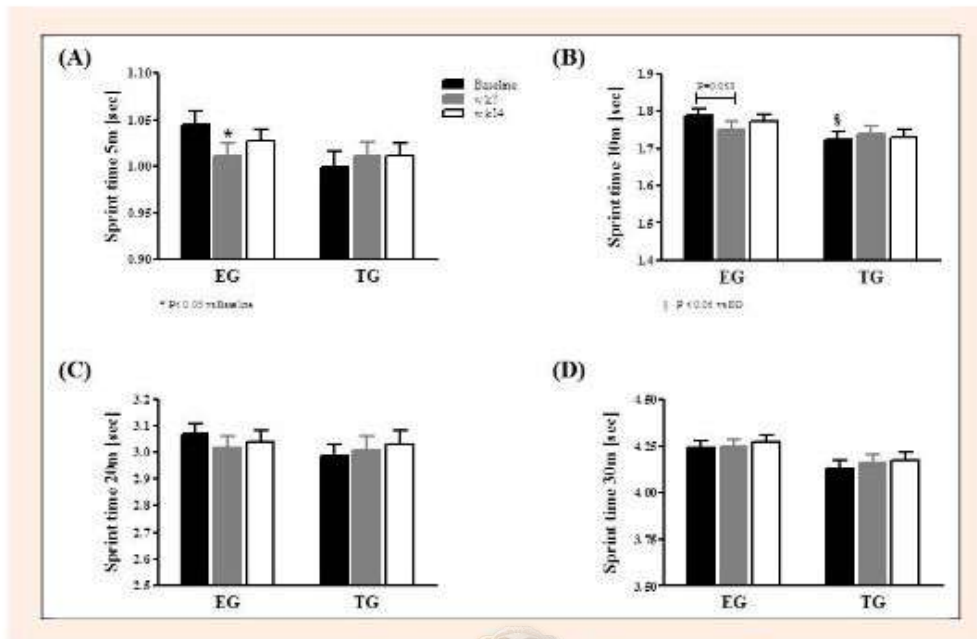


Figure 4. Linear Sprint performance at 5m (A), 10m (B), 20m (C), and at 30m (D) in EMS-Group (EG) and Jump-Training-Group (TG) measured before (baseline) after wk 7, after wk 14. Values are presented in means \pm SD, and significant differences at $p < 0.05$ (*).

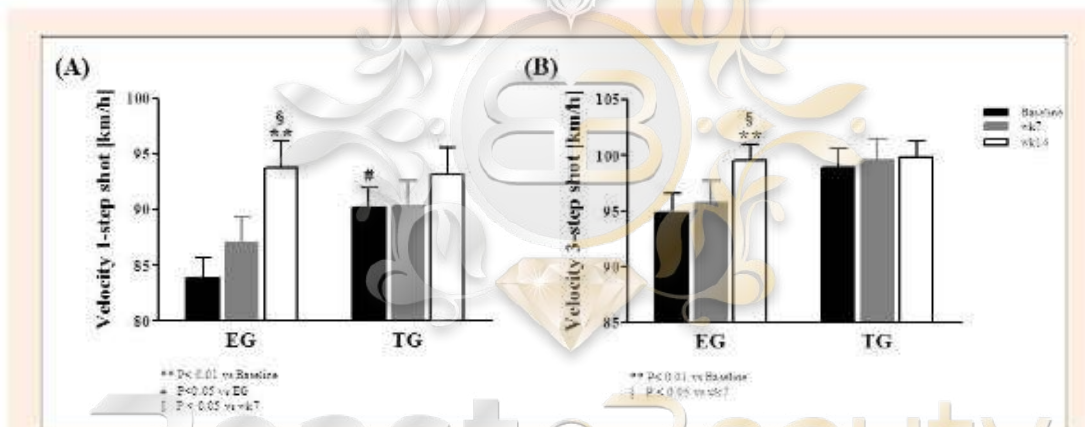


Figure 6. Kicking velocity (Ball speed $\text{km}\cdot\text{h}^{-1}$) with 1 step run-up (A) and 3 steps run-up (B) in EMS-Group (EG) and Jump-Training-Group (TG) measured before (baseline) after wk 7 and after wk 14. Values are presented in means \pm SD, and significant differences at $p < 0.05$ (*) and $p < 0.01$ (**).

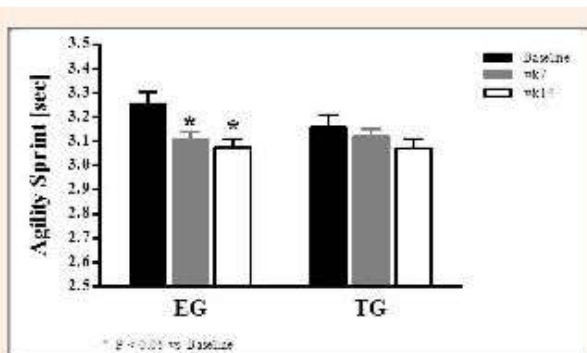


Figure 5. Sprint performance with direction changes over 15m in EMS-Group (EG) and Jump-Training-Group (TG) measured before (baseline) after wk 7 and after wk 14. Values are presented in means \pm SD, and significant differences at $p < 0.05$ (*).

Correlations: At wk7 we documented a significant

correlation between the gains (wk7-baseline) in leg press 1RM and the improvement in SJ performance ($r = 0.422$, $p = 0.047$) and linear sprint at 5m ($r = -0.470$, $p = 0.021$). Further, the analysis showed significant correlations between improvements in SJ and CMJ ($r = 0.526$, $p = 0.009$), linear sprint at (5m: $r = -0.601$, $p = 0.003$; 10m: $r = -0.497$, $p = 0.013$) and sprinting with direction changes over 15m ($r = -0.397$, $p = 0.042$). For CMJ the analysis showed significant correlation for sprinting with direction changes ($r = -0.602$, $p = 0.003$) and kicking velocity (1step: $r = 0.402$, $p = 0.049$; 3step: $r = 0.556$, $p = 0.008$). At wk14 we documented a significant correlation between the gains (wk14-baseline) in leg press 1RM and the improvement in CMJ performance ($r = 0.475$, $p = 0.02$). Correlations for squat jump were significant with gains in SJ performance ($r = 0.671$, $p = 0.001$) and kicking velocity (1step: $r = 0.558$, $p = 0.008$; 3step: $r = 0.510$, $p = 0.015$). For countermovement jump the analysis showed significant correlation between gains in CMJ performance and

sprinting with direction changes ($r = -0.400$, $p = 0.045$) and kicking velocity (1step: $r = 0.497$, $p = 0.018$; 3step: $r = 0.481$, $p = 0.022$). Further, we documented correlations between the gains in DJindex and the improvements in linear short sprint (5m: $r = -0.78$, $p < 0.001$; 10m: $r = -0.61$, $p = 0.002$), and kicking velocity (1step: $r = 0.43$, $p = 0.01$; 3step: $r = 0.448$, $p = 0.31$). We documented no significant correlations between the gains of the other parameters.

Effects on blood parameters

Creatine kinase (CK): Concerning the long-term effects, we observed a non-significant main effects for factor time ($F = 3.692$, $d = 11$, $p = 0.056$, $\eta^2_p = 0.402$), and a significant time*group effect ($F = 4.967$, $p = 0.029$, $\eta^2_p = 0.475$). The post-hoc analysis showed a significant increase of CK for EG only at wk7 ($p < 0.05$) compared to baseline. Regarding the acute effects, we observed a significant increase of CK from pre to 24h post for EG in the first session at baseline ($p < 0.01$) and in the tests at wk7 ($p < 0.05$). There was no significant acute increase at wk14. In the TG, CK remained unchanged to baseline till wk14. No differences were observed between pre to 24h post values in all tests.

For group comparison, the EG showed a significant higher pre CK value ($p < 0.05$) and 24h post value ($p < 0.01$) compared to the TG at wk7. There were no significant differences in the pre and 24h post CK values at baseline and wk14 (Figure 7).

Insulin-like growth factor-1 (IGF-1): Regarding the IGF-1 we observed no significant main effect for time and time*group. Both groups showed no significant changes in the pre IGF-1 values from baseline to wk14. Regarding the acute effects the analysis showed no changes from pre to 15-30min post and 24h post intervention for EG and TG. There was no significant group difference between the groups in all tests.

Discussion

The main findings of this study were that two WB-EMS sessions in addition to 6-7 soccer training sessions per

week over 7-14 weeks (14-28 sessions) can be sufficient to enhance physical performance such as leg press 1RM, jumping and sprinting performance, and kicking capacity in professional soccer players. However, jumping and kicking performance showed delayed adaptations and were not significant after 7 weeks. Regarding strength adaptations, we observed no effect on IGF-1 and no changes in body weight that both could have indicated a hypertrophy effect. In contrast to the TG CK values were strongly increased after WB-EMS sessions.

Effects on strength and performance

In regards to maximal strength (1RM) the professional soccer players in this study showed significant increases in leg strength (1RM) of $+16.83 \pm 13.06\%$ after 7 weeks (14 sessions) and $+22.42 \pm 12.79\%$ after 14 weeks (28 sessions) of dynamic WB-EMS. These gains in maximal strength (1RM) have not been shown by studies using WB-EMS yet (Boeckh-Behrens and Treu, 2002; Boeckh-Behrens and Mainka, 2006; Kreuzer et al., 2006; Speicher and Kleinöder, 2009). Considering maximal strength and jumping performance our results are in line with the findings of studies using local EMS-training (12-28 sessions) on the lower body muscles in trained and elite athletes (Babault et al., 2007; Filipovic et al., 2012; Kots and Chwilon, 1971; Maffiuletti et al., 2000, 2002; Willoughby and Simpson, 1998). Regarding the parameters of speed strength and power, the studies by Kreuzer et al. (2006) and Speicher et al. (2009) using isometric and dynamic WB-EMS achieved only low gains in maximal strength but remarkable gains in rate of force development and force impulse after four weeks (8 sessions), but couldn't transfer the gains into jumping performance. One reason for this could be the difference between training movement and test movement (e.g. isometric vs. dynamic), which can hamper the transfer. A further reason could be the relatively short study duration of four weeks and the lower number of training sessions. Compared to this study (8 vs. 14 sessions) strength parameters might need more than 8 sessions respectively longer time to develop.

In this study strength gains in the EG could directly transfer to the players' performance and result in a

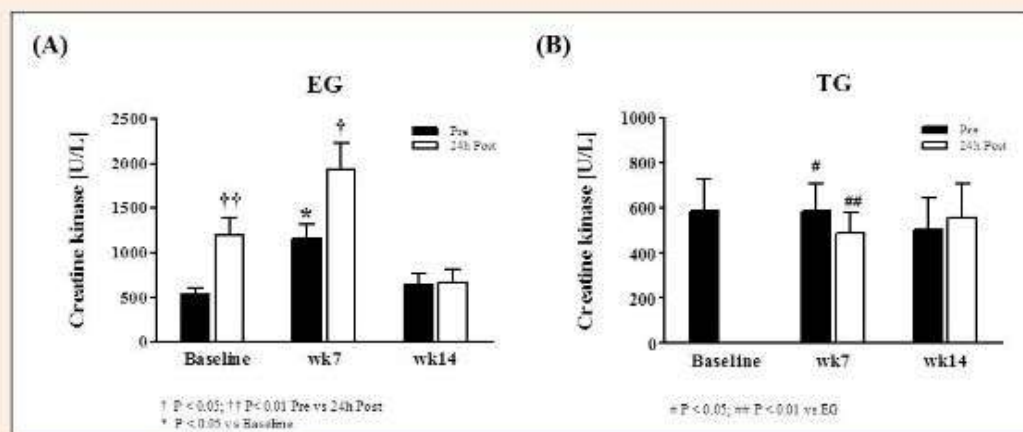


Figure 7. Creatine kinase (CK) levels in the (A) EMS-Group (EG) and (B) Jump-Training-Group (TG) at baseline, wk 7 and wk 14. CK was measured in the blood serum before (pre) and 24h after (24h post) the training interventions. Values are presented in means \pm SD, and significant differences at $p < 0.05$ (*) and $p < 0.01$ (**).

significant improvement of jumping, sprinting, and kicking performance. According to this, we documented a significant correlation between the gains in leg press 1RM and the improvement in squat jump performance ($r = 0.422$, $p = 0.047$) and linear sprint at 5m ($r = -0.470$, $p = 0.021$) in wk7 (wk7-baseline). Further, the analysis showed significant correlations between improvements in squat jump and linear sprint at 5m ($r = -0.601$, $p = 0.003$), at 10m ($r = -0.497$, $p = 0.013$) and sprint with direction changes over 15m ($r = -0.397$, $p = 0.042$). In comparison to the EG, the maximal strength (1RM) in leg press remained unaltered in the TG during the study. That argues for the stagnation in jumping and sprinting performance. Furthermore, these results suggest that on a high-performance level 30 maximal squat jumps twice a week, as applied in this study (work/rest: 4s/10s), are not sufficient to enhance leg strength or jumping performance in elite soccer players.

Studies have shown that the strength of the m. quadriceps femoris and especially the reactive ability of the m. triceps surae influence jumping and sprinting performance (Weineck, 2007; Wissloff, 2004). Considering reactive strength ability, we documented correlations between the gains in DJindex (wk14-baseline) and the improvements in linear short sprint (5m: $r = -0.78$, $p < 0.001$; 10m: $r = -0.61$, $p = 0.002$), and kicking velocity (1step: $r = 0.43$, $p = 0.01$; 3step: $r = 0.448$, $p = 0.31$), and a trend in sprinting with direction changes ($r = -0.379$, $p = 0.055$) from baseline to wk14 (wk14-baseline). Accordingly, the stimulation of the calve muscles in addition to the thigh muscles, seem to have a positive effect on the reactive strength ability and thus on drop jump and sprint performance (linear and multidirectional). Our findings support the results from previous EMS-studies that showed positive effect of the additional stimulation of the m. triceps surae on performance (cf. Filipovic et al., 2012). For example, Maffiuletti et al. (2002) stimulated the m. quadriceps femoris and the m. triceps surae of professional volleyball players over four weeks (12 sessions) in combination with a plyometric jump training. The authors documented significant increases in maximal strength in both muscle groups of $>25\%$ and showed increases of $>20\%$ in SJ performance and $>10\%$ in DJ performance. In comparison, after 7 weeks (14 sessions) we documented increases of $+16.83 \pm 13.06\%$ in 1RM leg press, $+4.23 \pm 7.71\%$ in SJ, $+9.98 \pm 20.96\%$ in DJindex, $-1.77 \pm 2.34\%$ in 10m linear sprint, and $-4.92 \pm 3.76\%$ in sprint with direction changes.

However, this study design does not allow to conclude that WB-EMS alone is sufficient to increase maximal strength and soccer relevant performance parameters.

Possible adaptation mechanisms

In regards to the strength adaptations we documented no changes in body weight after 14 weeks of EMS training. Furthermore, the WB-EMS showed no acute or long-term effects on IGF-1. Growth factors such as IGF-1 or hgH play an important role during tissue remodeling (cf. Kramer and Ratamess 2005) and can be indicators for a hypertrophy effect. Jubeau et al. (2008) investigated the acute effect of EMS on human growth hormone (hgH).

They observed a significant greater increase in hgH and creatine kinase activity for the EMS-group compared to voluntary exercise. Gondin et al. (2011) applied EMS to the m. quadriceps femoris of trained athletes three times a week in addition to the usual sport specific training (4-6 hours a week). The authors observed a significant hypertrophy effect of 12% in type-I and 23% in type-II fibers together with an increase in cross sectional area of the m. quadriceps femoris after 8 weeks. The total time under tension in this study was 12.5 minutes per week (40 contractions per session, 6.25s on/20s off). In contrast, in the present study the time under tension was two minutes per session (30 contractions, 4s on/10s off) and only four minutes per week total. The lower time under tension and or the lower number of sessions per week might not be sufficient to affect growth factors such as IGF-1 and subsequently activate hypertrophy mechanisms. According to the results of this study, two WB-EMS training session per week in addition to 6-7 soccer sessions seem to have no effect on hypertrophy in elite soccer players.

Strength transfer

In the present study strength gains in one-legged 1RM at the leg press machine could directly be transferred to an improved performance in linear sprinting and sprinting with direction changes within 7 weeks (14 sessions). However, jumping and kicking velocity showed delayed adaptations and were not significant before wk14 (28 sessions). The findings reveal that strength gains achieved with WB-EMS might need a longer adaptation period (>7 weeks) when applied twice a week or a higher number of EMS-sessions per week or longer time under tension per session respectively to transfer into jumping and kicking performance within 7 weeks. Further, an highly increased stress load through EMS training in addition to the normal training/game load might negatively influence or hamper strength transfer. An additional specific plyometric training could have positively influenced the strength transfer into explosive movements such as jumping and kicking.

Compared to previous studies we only conducted two EMS sessions per week (vs. 3-4 sessions) and thus had a lower total time under tension per week (4 vs. 5-8 min) (Herrero et al., 2006; Maffiuletti et al., 2000; 2002; Babault et al., 2007; Billot et al., 2010; Malatesta et al., 2003; Pichon et al., 1995). Similar to our study design, Billot et al. (2010) investigated the influence of an EMS-training (3 sessions/wk, 5.4 min time under tension/wk) in trained (semi-professional) soccer players. After five weeks (15 sessions) the authors documented a significant improvement in dynamic leg strength and in kicking velocity. In line with our findings, the players showed no changes in vertical jumping and 10m sprinting performance after 14 sessions. Taking this in account, our findings suggest that speed strength parameters such as jumping and kicking might need more than 14 sessions or a higher total time under tension per week to significantly improve within 5-7 weeks. However, to our knowledge this was the first study that implemented WB-EMS in the training routine of professional soccer players over a period of 14 weeks. We designed this study on the basis of our previous investigation (cf. Filipovic et al., 2011).

According to this, we planned to include three WB-EMS-sessions per week in addition to the usual training routine. However, due to the lack of research with elite soccer players and the high training volume and intensity we reduced the WB-EMS sessions to two sessions per week in order to prevent the players from overtraining.

Regarding the training intensity, we observed a significant ($p < 0.05$) increase in CK in the EG at baseline (pre 530.30 ± 230.00 U/l, 24h post 1199.89 ± 569.69 U/l). Due to the constant increase of the stimulation intensity (e.g. thigh electrodes $+31.8 \pm 39.4\%$) in addition to a significant higher training load during the first six weeks (season preparation) the CK in the EG remained on a very high level ($p < 0.05$) till wk7. We observed no significant increase in CK in the TG compared to baseline during the study. The summation of higher training load and WB-EMS-training during the first 7 weeks might be overloaded some players' muscular system that might have hampered or delayed strength transfer. For comparison, we documented an average CK of 300-500U/l in a normal training week in the first half of the season with 6-7 training sessions per week. Nedelec et al. (2014) documented CK values of >700 U/l after 90 minutes of game play in professional soccer players. Our findings are in line with the results by Jubeau et al. (2008) showing that EMS training can release significant higher CK compared to voluntary exercise. From wk7 till wk14 CK values dropped again to baseline pre level together with a further increase in 1RM, jumping, sprint with direction changes and kicking velocity.

Conclusion

Two dynamic whole-body EMS sessions in combination with 30 squat jumps (12 minutes) concurrently to 6-7 soccer training sessions per week and one match are sufficient for effectively enhancing maximal strength, sprinting and jumping performance, and kicking capacity in professional soccer players. Strength gains achieved with WB-EMS might need more than 7 weeks (14 sessions) to significantly influence jumping and kicking performance when only applied twice a week.

Our findings indicate that WB-EMS training, as new stimulus, can complement or modify the common training structure and thus is able to enhance the athletic performance even of highly trained athletes.

Further studies are needed to enlarge the knowledge about practical application in this field and in view of possible undelaying mechanisms such as muscle hypertrophy or muscle fiber shift. EMG-analysis may contribute to gain knowledge about EMS induced neuronal adaptations in further studies.

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Key points

- Two WB-EMS sessions concurrently to 6-7 soccer training sessions per week enhanced maximal strength in the leg press machine within 7 weeks during competitive season.
- Sprinting and jumping performance and kicking capacity were improved after 14 weeks.
- WB-EMS did not effect serum IGF-1 levels in professional soccer players.

AUTHOR BIOGRAPHY



Andre FILIPOVIC

Employment

PhD candidate, Assistant soccer coach

Degree

Diploma in exercise science

Research interests

Physiology of soccer

E-mail: Andre.Filipovic@gmx.net

Marijke GRAU

Employment

Research group leader

Degree

PhD

Research interests

Nitric oxide metabolism

E-mail: M.Grau@dshs-koeln.de

Heinz KLEINÖDER

Employment

Research group leader

Degree

PhD

Research interests

Exercise science

Philipp ZIMMER

Employment

Research group leader

Degree

PhD, PhD

Research interests

Exercise immunology

Wildor HOLLMANN

Employment

Professor em.

Degree

MD

Research interests

Sports medicine

Wilhelm BLOCH

Employment

Head of department

Degree

MD

Research interests

Molecular and cellular

✉ Andre Filipovic

Roonstrasse 54, 50674 Cologne, Germany