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Research article

Can A Superimposed Whole-Body Electromyostimulation Intervention Enhance the Effects of a 10-Week Athletic Strength Training in Youth Elite Soccer Players?

Oliver Ludwig [1]✉, Joshua Berger [1], Torsten Schuh [2], Marco Backfisch [1], Stephan Becker [1] and Michael Fröhlich [1]
[1] Department of Sports Science, Technische Universität Kaiserslautern, Kaiserslautern, Germany
[2] Nachwuchsleistungszentrum Saar (Youth Academy) SV 07 Elversberg, Elversberg, Germany

Abstract

Strength training in youth soccer has both a preventive and a sports-specific component. Whole-body electromyostimulation (WB-EMS) could represent an interesting time-saving add-on to classical strength exercises in performance-oriented soccer. The objective of this study was to find out whether a 10-week superimposed WB-EMS training might have a more positive impact on strength parameters in male youth elite soccer players than regular athletic strength exercises alone. A total of 30 male youth soccer players from a youth academy aged 15 to 17 years participated in the study. Before and after the intervention, the isometric extension and flexion forces of trunk and knee, and the hip abduction and adduction forces were tested. Twelve players (control group) absolved a conventional 20-minute strength training once a week for a period of ten weeks. Eighteen players absolved the same exercises but with superimposed WB-EMS. Blood creatine kinase concentration was measured for training control. ANOVAs, Friedman tests and post hoc t-tests were calculated ($p = 0.05$) to examine the strength development during the training period between the groups. While we could not find significant strength increases in the leg, hip and trunk muscles in the control group (<4%), the strength of the WB-EMS group improved significantly in 4 of the 6 muscle groups tested. In this group, the strength of knee flexors increased significantly by 20.68 ± 21.55%, knee extensors by 31.43 ± 37.02%, hip adductors by 21.70 ± 12.86% and trunk flexors by 33.72 ± 27.43%. The rates of strength increase are partly in line with other studies, partly clearly higher, which might be explained by the athletically active target group. A 10-week superimposed WB-EMS training improves the strength of certain leg, hip and trunk muscles in male adolescent elite soccer players to a greater extent than a pure athletic strength training of the same duration.

Key words: WB-EMS, youth soccer, athletic training, core muscles, physical performance.

Introduction

Over the past few years, physical requirements have changed for youth soccer players (Elferink-Gemser et al., 2012). The performance required of the players is increasing steadily, especially in terms of physical performance to keep up with national and international competition (Finn and McKenna, 2010; Gonaus et al., 2019). Explosive strength and high intensity movements, such as jumps, sprints, and quick changes of direction, have increased in modern soccer (Di Salvo et al., 2009; Faude et al., 2012; Harper et al., 2019; Ingebrigtsen et al., 2015; Young, 2006), all of which has led to comprehensive athletic training having become indispensable in youth soccer.

Athletic training comprises various sports-related aspects, such as endurance, coordination, flexibility, and strength (Jovanovic et al., 2011). Strength training, though, consists of multiple components itself: maximum strength, power, reactive strength, and strength endurance. While the first components are training-relevant for many moves typical for soccer (Al Attar et al., 2017; Silva et al., 2015), strength endurance is especially important for the trunk's postural musculature (Barczyk-Pawelec et al., 2015). It is known that a large proportion of adolescents suffer from posture weakness, mostly caused by insufficient static strength development of trunk and pelvic muscles (Buchtelová et al., 2013; Frank et al., 2009). Strength training in (soccer) athletics is therefore key to promote a stable trunk and pelvic musculature ('core muscles'). Furthermore, muscular imbalances seem to be risk factors in terms of soccer-specific injuries, such as ruptures of the anterior cruciate ligament (Alentorn-Geli et al., 2009). Therefore, targeted strength training can play a key role in injury and pain prevention (Pfirrmann et al., 2016). At the same time, maximum strength and power should be improved, and thus soccer-relevant movements like jumps, sprints, quick changes of direction be optimized and the kicking force increased (Manolopoulos et al., 2006). Obviously, strength training in soccer has both a health-related, preventive and a sports-specific component (Junge and Dvorak, 2004; Pfirrmann et al., 2016; Silva et al., 2015). The medical officers of national and international soccer associations therefore recommend the integration of strength training into soccer specific training (Bizzini and Dvorak, 2015; Barengo et al., 2014). Hoff and Helgerud (2004) emphasize in this context that new developments and methods in (strength) training should be followed and training practices adapted accordingly.

The growing pressure to perform and increasing training scopes pose a time problem for performance-oriented youth soccer: weekly training time is limited but supposed to include all kinds of training content (Finn and McKenna, 2010). In addition, sufficient time for regeneration is required. This calls for training types comprising intensive content at a minimum amount of time.

Electromyostimulation (EMS) could therefore be an interesting addition to classical athletic training. The stimulation of muscles through electrodes applied to the skin has been known for a long time from the field of physical

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therapy (Morrissey, 1988; Park et al., 2016). Filipovic et al. (2012) showed in a review that EMS can also be used in sports to optimize training and improve individual strength abilities (e.g. maximal strength, speed strength, and power). The consequence seems to be an improved neuromuscular recruitment of muscle fibers (Maffiuletti, 2010) but also muscular adaptions as muscle fiber shift or muscle hypertrophy (Thériault et al., 1996).

Whole body (WB)-EMS goes one step further: it does not only simultaneously stimulate many muscle groups, but also includes active movement during the stimulation. Recent studies report promising results in both adult soccer players (Filipovic et al., 2019; Filipovic et al., 2016) and untrained persons (Kemmler et al., 2016b; Ludwig et al., 2019). It is generally agreed that a WB-EMS training due to the high muscular load should only last a short time (in general 10-20 minutes), meaning it is highly attractive if training time is a limiting factor. Filipovic et al. (2012) clarify that in contrast to voluntary exercises, WB-EMS leads to an artificial (increased) muscle contraction without a resistance load, and therefore, conventional training programs cannot be simply transferred into WB-EMS strength training. In further studies, Filipovic et al. (2016; 2012) found that WB-EMS can be an effective alternative to conventional resistance training to improve maximal strength in adult elite athletes.

For this reason, even though device-related investments are still high (several thousand euros), WB-EMS could represent an interesting add-on to classical strength exercises in performance-oriented youth soccer, especially because it seems to be highly motivating for older adolescents. However, to date there are no studies on utilizing WB-EMS in the youth soccer field.

Therefore, the objective of this study was to find out whether a 10-week superimposed WB-EMS training taking place once a week might have a more positive impact on maximal strength parameters in male youth elite soccer players than regular strength exercises.

We expected that identical strength exercises performed once a week in the same subjective strain range will possibly achieve a greater increase in maximum strength within 10 weeks when WB-EMS is superimposed.

Methods

Participants

A total of 32 male youth soccer players from a youth academy aged 15 to 17 years participated in the study. They played in the second-highest league in Germany (‘Regionalliga’) for this age group. All players belonged to the same club and were trained by the same soccer and athletics coach. Their typical training included four training sessions per week; one of them was a 45-minutes athletic training session, including a 20 min strength training unit, plus one match.

The initial examinations and the familiarization phase took place during the pre-season period, the training sessions during the current soccer season.

All junior players were uninjured and free of orthopedic and internal disorders at the time of the initial measurements. The players had previously undergone internal and orthopedic examinations as part of the routine check-ups prescribed by the German Football Association (DFB). Developmental parameters (e.g. tanner stages) were also recorded as standard. There were no physically retarded players in the examined group of subjects, the biological age was classified as Tanner 5 and 6, and there were no differences between the control and intervention group in the anthropometric and developmental parameters (see Table 1 for anthropometric data).

The division of the players into the two groups was not randomized but had to be determined on the basis of logistical considerations. Since many players from more distant regions were driven to training by a central transport service, they had to be scheduled into the same group. However, the percentage distribution of players between the two groups according to their playing position was still roughly balanced (Table 1). Since the national soccer association requires the exact recording of training and match times in youth academies, it was possible to subsequently document the sporting load during the study (Table 1).

Two players of the control group had to drop out during the intervention phase due to non-contact injuries (muscle fiber injuries) sustained during their league matches, so they were not able to participate in all of the athletic training sessions and the post-tests. Therefore, data of only 30 players were analyzed.

The study was approved by the local ethics commission and conducted in accordance with the Declaration of Helsinki. The players and their parents had been informed on the intention and order of the study and had given their written consent.

Strength tests

Before and after the 10-week athletic training, the maximal isometric trunk extension and flexion forces were tested by means of Back Check 607 (Dr. Wolff, Arnsberg, Germany). Before the strength tests, the players carried out a ten-minute warm-up program. This consisted of sprints, skipping, jumps, dynamic stretching and movement preps (Needham et al., 2009) and was already familiar to the players as part of their regular athletic training.

Table 1. Anthropometric and operational data of the WB-EMS training group (EMS) and the control group (CON).

	Age [years]	Height [m]	Weight [kg]	Playing position S/M/D/G †	Mean playing time [min]
EMS (n = 18)	16.28 ± 0.67	1.76 ± 0.04	67.25 ± 5.30	N: 6/4/7/1 %: 33/22/39/6	428.3 ± 214.9
CON (n = 12)	16.42 ± 0.90	1.79 ± 0.05	70.84 ± 6.08	N: 4/3/4/1 %: 33/25/33/8	450.8 ± 163.3

† Distribution of playing positions in absolute numbers (N) and percentage (%), S – striker, M – midfielder, D – defender, G – goalkeeper.

During the tests, the athletes stood in the test apparatus with slightly bent knees and arms hanging down loosely. A ventral and a dorsal pad were used to fixate the pelvis in the sagittal plane. One pad with a force transducer was placed between the shoulder blades and one at sternum level. The participant was to perform a forward bend, i.e., press against the sternum pad at maximum strength for 5 seconds and, after a 30-seconds break, perform a maximum trunk extension, i.e., press against the back pad for 5 seconds at maximum strength. Other studies proved the reproducibility of this type of isometric measurement (Scheuer and Friedrich, 2010).

Knee flexion and extension were measured in a sitting position by means of the EasyTorque device (Fa. Tonus, Zemmer, Germany). The knee angle was set to 80 degrees for measuring the knee flexion; the hip angle was set to 90 degrees. Hip and thighs were fixated with pads, and the pads with force transducers were positioned dorsally or ventrally at the lower part of the tibia. The same device was used to measure the maximum strength of hip abduction and adduction in a sitting position (hip and knee angle at 90 degrees each). The pads with force transducers were positioned in the area of the knee joints (medial or lateral). The tests were always performed in the same order: trunk flexion/extension, knee flexion/extension, hip abductors, hip adductors. After a trial run, all isometric measurements were repeated three times. Whenever the third value turned out to be the maximum value, further measurements were conducted after a 30-seconds break until the last measurement value was smaller than the penultimate value. Only the best value was used for further analysis.

Training

Fourteen of the players were assigned to the control group which absolved only the conventional 20-minute strength training during the study period without superimposed WB-EMS. Eighteen players were assigned to the EMS group.

During the weekly athletic training, for all study participants of both groups one 20-minute strength training session was included that consisted of ten static and dynamic exercises. The exercises were chosen to train maximum strength, strength endurance, and explosive strength. Figure 1 shows an overview of the exercises performed.

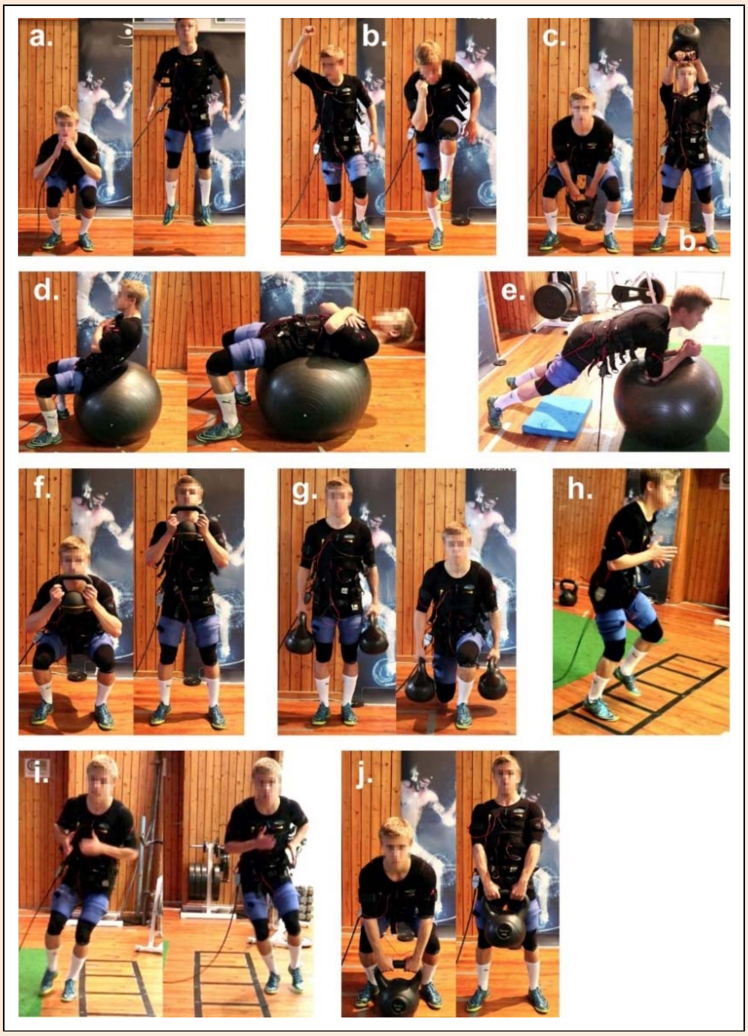

Figure 1. Overview of the athletic exercises. a. counter movement jump, b. diagonal crunches in standing position, c. kettle bell swing, d. crunches on the gym ball, e. static plank on the gym ball, f. squat with kettle bell, g. walking lunches with kettle bell, h. coordination ladder lateral, i. coordination ladder frontal, j. trunk extension.

The strength training was carried out on several days when no soccer training took place.

Some exercises were made more difficult by additional standardized weights that were the same for each participant (12 and 24 kg-kettle bells, details in table 2). The WB-EMS group performed the same exercises as the control group, the only difference being that muscles were stimulated electrically during the exercise and that their movement speed during the dynamic exercise series was strictly regulated. Each exercise series was performed for one minute with a one-minute break between the individual exercises. This timing has proven to be very useful in order to be able to change body positions and pick up the additional weights in a controlled way.

The WB-EMS group performed the dynamic exercises during the one-minute exercise series in a 4 seconds time-under-current application / 4 seconds break rhythm. During the 4-s time-under-current period two complete movements were performed (concentric phase - 1 second, eccentric phase - 1 second), i.e. a total of 15 movements per minute. Only in the exercises with the coordination ladder (Figure 1 h + i) the movement was performed continuously during the 4 seconds time-under-current period. In all cases the current was adjusted so that the physical strain was rated 6-7 ('moderate' to 'strong') on the RPE scale. In the control group, the technique of exercise execution was the same, but the number of movements within the one-minute exercise series was selected by the athletes so that the strain was also rated 6-7 on the RPE scale. For exercises b, d, f, g and j (Figure 1), the control group should go through the concentric movement phase as quickly as possible, the eccentric phase should be controlled, about 1 second duration.

During the static exercise (Figure 1e), the participants were instructed to keep the position they had taken stable for one minute under isometric tension. In the WB-EMS group the current was applied in 4s/4s intervals. Both groups were instructed to hold the static position for one minute, to tense their buttocks, shoulder and abdominal muscles and to continue breathing normally. Table 2 summarizes the target muscles and instructions.

All exercises were instructed by the same coach (the athletics coach of the club). The WB-EMS application was additionally monitored by the same assistant.

Training control

The training was controlled by the individual grading of the strain by the participants using the RPE scale. This is a reasonable and proven method for training control with WB-EMS, because in contrast to local EMS the output parameters of the devices (current or voltage) are displayed only in arbitrary units and not used for training control. WB-EMS is designed for use in non-medical areas. Therefore no preparation of the skin (to reduce the electrical

Table 2. Exercise instructions and target muscles

#	Exercise	Instructions	Strength component & target muscles
a	Counter movement jump	Jump up from the squat position as explosively as possible. CON: Do as many reps as possible. WB-EMS: Make two jumps per current application	Power: leg extensors
b	Diagonal crunches	Roll up the upper body and bring opposite elbow and knee together. Change sides after each repetition. CON: Do as many repetitions as possible. WB-EMS: Make two movements per current application	Strength endurance: abdominal muscles, hip flexors
c	Kettle bell swing (12 kg kettle bell)	Swing the kettle bell upwards with outstretched arms, knees go from flexion to extension. CON: Do as many repetitions as you can. WB-EMS: Make two swings per current application	Strength endurance, Power: leg extension, trunk extensors
d	Crunches on gym ball	CON: Make as many crunches as possible, unrolling the back as much as possible. WB-EMS: Make two crunches per current application	Strength endurance: abdominal muscles
e	Plank on gym ball	CON+WB-EMS: Hold the position for 1 minute, keep the trunk as straight as possible, tighten shoulder, abdominal and buttock muscles, continue breathing normally.	Strength endurance: abdominal muscles, buttocks, knee extensors
f	Squat with kettle bell (24 kg)	Keep the kettle bell stable in front of the chest CON: Make as many squats as possible WB-EMS: Make two squats per current application, keeping the kettle bell stable in front of the chest	Strength endurance: leg extensors, trunk extensors
g	Lunches with kettle bell (2x 12 kg kettle bell)	Keep the trunk straight, change sides after each repetition. CON: Make as many lunches as possible WB-EMS: Make two lunches per current application	Strength endurance: leg extensors, trunk extensors
h	Coordination ladder lateral	CON+WB-EMS: Run the coordination ladder laterally with triple steps as fast and as often as possible	Strength endurance: leg muscles, hip abductors
i	Coordination ladder frontal	CON+WB-EMS: Run the coordination ladder from front to back with triple steps as fast and as often as possible	Strength endurance: leg muscles
j	Trunk extension with kettle bell (24 kg)	Go from the bent position to a trunk extension as fast as possible. Keep the upper body stable. CON: Repeat this as often as possible WB-EMS: Make two trunk extensions per current application	Strength endurance, Power: trunk extensors, knee extensors, buttocks

Letters (#) refer to figure 1. Only the main muscle groups are mentioned.

resistance) takes place, but moistened functional underwear is placed between skin and electrodes. The load is selected on the basis of device-specific (arbitrary) units and not on absolute measured values (voltage, current). The control of the load by the sensation of the test person has the advantage that temporary physiological changes (e.g. a reduction of the skin resistance due to sweating) within and between the training sessions can be compensated. During the 10-week training period no constant increase of the device output parameters was specified, but a constant subjective strain in the RPE range of 6-7 was maintained. To ensure this, depending on the daily subjective feeling, WB-EMS applications regularly required the output power of the device to be increased or reduced. The method of subjective strain control has proven itself many times in this setting (Filipovic et al., 2012; Kemmler et al. 2018).

A Miha Bodytec 2 device (Miha Bodytec, Augsburg, Germany) was used for the WB-EMS application. The participants wore electrically conductive functional underwear and training vests with integrated large electrodes. Ring-shaped Velcro electrodes were fixed around arms and thighs, and a belt with the buttock electrodes around the hip. These electrodes were connected to the vest via cables. A 2-meter long cable connected the vest with the Miha Bodytec 2 device. The wetted electrodes were placed above the following muscle groups that were electrically stimulated during the WB-EMS training: upper arms, quadriceps, hamstrings, gluteal muscles (each with velcro electrodes), straight and oblique abdominal muscles, pectorals, lower and upper back (integrated in the vest). During the training, always all muscles were stimulated simultaneously, during the dynamic exercises both in the concentric and the eccentric movement phase. The stimulation corresponded to the generally accepted parameters examined in earlier studies: impulse width 350 µs, stimulation frequency 85 Hz, bipolar rectangular impulse, 4 s load – 4 s break intervals (Kemmler et al., 2018; Ludwig et al., 2019; Berger et al., 2020). The Miha Bodytec 2 system enables a separate output control for each of the 8 available channels. During the training, the intensities were queried from the athlete during every exercise and adjusted by the EMS trainer to render the training intensity demanding, but not painful.

Before the training started, all study participants (control and intervention group) were familiarized with the RPE scale (rating of perceived exertion; 0 = no exertion, 10 = maximum exertion (Borg and Kaijser, 2006)). All exercises were performed in the 6-7 range ('moderate' to 'strong'). The training data of the WB-EMS group was saved on an individual chip card after each session.

During a 10-week period, the strength exercise sessions were performed once a week and for each athlete always at the same time of day. The first training session had the purpose for both groups to learn the correct execution of the exercises and for the WB-EMS group to get accustomed to the electric stimulation (Kemmler et al., 2018). Before each training session, the test persons were questioned by means of a standardized check list about their current health status. This was meant to identify any potential contraindications (e.g., pain, dizziness, nausea, intake of pain killers). At the same time, it was ensured that the test participants had drunk at least 500 ml liquids before training started. Both measures comply with the current WB-EMS training safety requirements (Kemmler et al., 2016a). The WB-EMS trainer supervised only one person at a time so that an exact execution of the exercises and an adjustment of current application were ensured.

During the training period, the players were instructed not to change their diet, not to take dietary supplements and not to practice any additional strength training.

Creatine kinase (CK) measurements

It is known that high (WB-) EMS exercise loads may have side effects, the most extreme being rhabdomyolysis with renal failure (Kästner et al., 2015; Nosaka et al., 2011). The electrical stimulation of the musculature by (WB-) EMS seems to cause increased muscular stress, probably due to the different recruitment of motor units compared to voluntary contractions (Jubeau et al., 2008). This is also assumed to be the reason for increased muscle fiber injuries and thus higher CK values (Boeckh-Behrens and Mainka, 2006). Since no data on WB-EMS pertaining to adolescent soccer players exist and the risk of their overestimating themselves during training cannot simply be dismissed, we analyzed the levels of creatine kinase in their capillary blood at the beginning and during the study to introduce an additional step of monitoring (Stöllberger and Finsterer, 2019). We defined a threshold of 1,000 u/l as a limit based on the reference intervals found by Mougios (Mougios, 2007). This constitutes a rather prudent value because it is known that frequent stop-and-go movements in soccer can definitely lead to higher values, just like in regular training and matches. Meyer and Meister found similar values (95% confidence interval: 107-1,327 u/l) in adult elite soccer players in the course of one season (Meyer and Meister, 2011). We wanted to be sure that the metabolic stress caused by our WB-EMS training, which is new to youth soccer, was not too great, also to meet the requirements of the ethics committee. Thus, the CK value assessment in this study was not used to evaluate possible training effects, but as a "safety parameter" to detect possible muscle overload at an early stage (Teschler and Mooren, 2019). It is known from other studies that in the context of WB-EMS training, there can be a strong increase in CK values during the first training sessions, especially if the test persons cannot yet estimate the load (Filipovic et al., 2016). Therefore, the values were only analyzed during the training period until a stable value of <1,000 u/l was reached.

Before the first WB-EMS training session, 72 hours after the first, and 72 hours after the second training session (Kemmler et al., 2015; Jubeau et al., 2008), the CK value in the capillary blood was determined (enzymatic analysis IFCC at 37 °C; Vario II photometer, Diaglobal, Berlin, Germany). At initial values above 1,000 u/l, the start of the WB-EMS intervention was delayed by a few days until the CK value fell below that threshold. This was the case for two participants. In five cases increased values occurred after the 1st or 2nd training session, whereupon the following training sessions were rescheduled by one week for the affected subjects, and the measurement of their CK values was repeated. 72 hours after the 8th training the CK values were determined for the last time. Figure 2 shows the timeline of the intervention and CK measurements.

Statistics

All statistical tests were calculated using XLSTAT 2019.3.2 for Windows (Addinsoft, Paris, France). The significance level was set to p = 0.05. The WB-EMS and control groups' anthropometric data were tested for significant differences by means of t-tests.

According to the Levene test, there was no variance homogeneity between WB-EMS and control group (p = 0.02) for the *trunk flexion* variable at PRE, and the WB-EMS group showed significantly lower strength values than the control group. Therefore, strength development of *trunk flexion* was analyzed over time using the Friedman test. For all other strength variables, variance homogeneity existed and therefore, five repeated 2x2 ANOVAs (group × time) were calculated based on the raw values for all strength parameters except *trunk flexion*. For all muscle groups, the differences before our intervention between the WB-EMS and CON groups were analyzed by t-tests (time 'PRE').

To represent differences between the training groups in the pre-post comparison, the strength increase percentage of the individual muscles were calculated additionally ($(F_{post}-F_{pre})*100/F_{pre}$), and then checked after Bonferroni-Holm correction for significant mean differences between the WB-EMS and control group by means of multiple t-tests.

Results

The anthropometric data of both groups (Table 1) did not differ significantly (age: t= 0.72, p = 0.48; height: t = 1.46, p = 0.16; weight: t = 1.63, p = 0.11). The force values of all muscle groups did not differ between WB-EMS and the control group at the time 'PRE' (see Table 3). Table 3 shows the muscle strength values before and after the intervention, and the strength increase percentages, Figure 3 shows the individual changes of the strength values within the two groups for all subjects. During the post-test, one player in the control group reported pain during hip adduction. As a result, he scored only 50% of the force value of his initial test. In this case, the test result was removed as an outlier.

The ANOVAs did not exhibit any statistically significant interindividual effects, but significant intraindividual effects for the factor *time* (for trunk flexion, knee extension and flexion, and hip adduction), as well as for the *group* × *time* interactions (for trunk flexion, knee extension and flexion, and hip adduction) with medium to high effect sizes (Table 4).

The Friedman test for the *trunk flexion* variable did not result in any statistically significant difference in the pre-post comparison for the control group (Q=0.00; p=1.00), but did indeed show a statistically difference for the EMS group in the pre-post comparison (Q = 14.22; p = 0.0002).

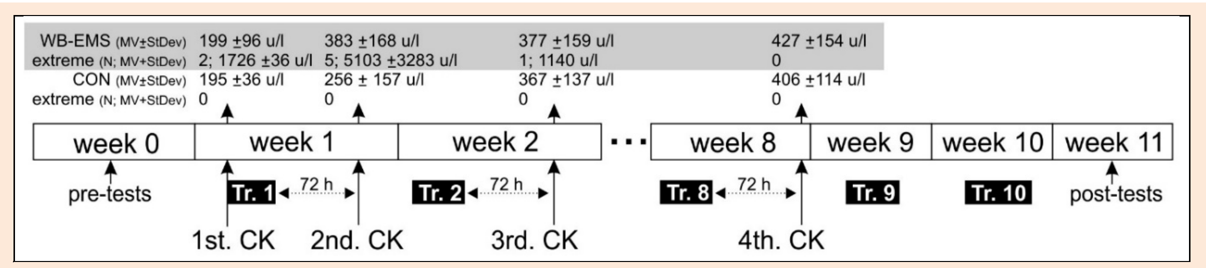

Figure 2. Timeline of the study with dates of the CK measurements. CK values for the 4 measuring times for WB-EMS and CON group with number of extreme values > 1,000 u/l (mean value ± standard deviation). Tr. = training, CK = CK measurement.

Table 3. Muscle forces of the PRE- and POST-tests (mean ± standard deviation) and percentage strength increases (Δ%).

Group	Muscles	PRE [N]	POST [N]	EMSPRE vs. CONPRE (t; p) #	Δ% POST-PRE [%]	Δ% EMS vs. Δ% CON (p_{adj}) ‡	Cohen's d
EMS (n = 18)	Trunk Flex	540.56 ± 89.11 †	717.22 ± 157.30	1.98; 0.07	33.72 ± 27.43	0.013 *	1.28
	Trunk Ext	715.56 ± 104.75	776.94 ± 109.48	1.63; 0.11	9.86 ± 16.42	0.288	-
	Knee Flex	619.81 ± 123.54	733.10 ± 124.05	1.15; 0.26	20.68 ± 21.55	0.020 *	1.18
	Knee Ext	996.37 ± 268.68	1270.14 ± 330.20	0.68; 0.50	31.43 ± 37.02	0.026 *	0.98
	Hip Add	1140.43 ± 181.78	1377.53 ± 208.67	1.31; 0.20	21.70 ± 12.86	0.001 *	1.61
	Hip Abd	1017.64 ± 157.81	1095.96 ± 150.98	0.73; 0.47	8.43 ± 10.74	0.365	-
CON (n = 12)	Trunk Flex	651.67 ± 179.84	655.83 ± 126.06		3.82 ± 18.64		
	Trunk Ext	776.25 ± 92.32	800.00 ± 109.30		3.11 ± 7.80		
	Knee Flex	668.11 ± 93.98	660.58 ± 127.10		-1.01 ± 14.52		
	Knee Ext	1069.93 ± 316.23	1096.91 ± 317.47		3.78 ± 14.53		
	Hip Add	1234.69 ± 198.28	1266.75 ± 232.93		-2.53 ± 17.47		
	Hip Abd	1071.19 ± 243.16	1082.97 ± 144.31		3.87 ± 16.45		

EMS = WB-EMS training group, CON = control group. † significant difference to CON at p= 0.05. Flex = flexors, Ext = extensors, Add = adductors, Abd = abductors. ‡ Bonferroni-Holm adjusted p-values of the multiple t-tests (Δ% POST-PRE values of the EMS group tested versus the CON group). # comparison of raw data of EMS and CON group at time 'PRE' with t and p values. * mark significant results at p < 0.05.

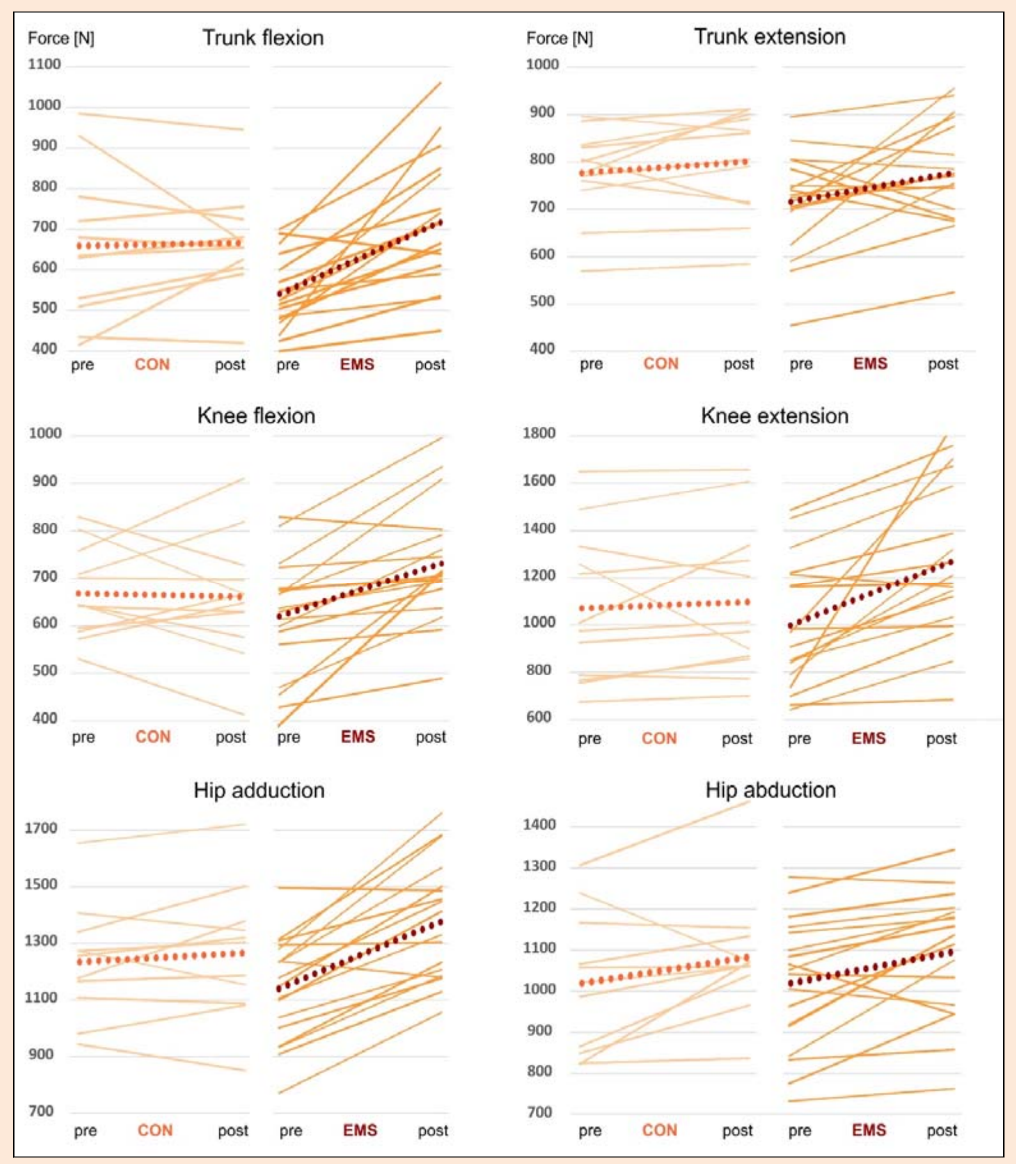

Figure 3. Force development in control group (CON) and EMS group (EMS) of the individual subjects in pre-post comparison. Dotted lines: mean values.

Table 4. Results of the 2x2-ANOVAs (inter- and intra-individual effects).

	Inter-individual effects	Intra-individual effects			
	Group F(1,28); p	Time F(1); p	η_p^2	Group x Time F(1,28); p	η_p^2
Trunk Flex		*not applicable (see text)*			
Trunk Ext	1.44; 0.24	5.8; 0.02 *	0.17	1.13; 0.29	(0.04)
Knee Flex	0.09; 0.77	8.3; 0.006 *	0.23	10.83; 0.002 *	0.28
Knee Ext	0.22; 0.64	11.08; 0.002 *	0.28	7.46; 0.008 *	0.21
Hip Add	0.01; 0.91	28.20; <0.001 *	0.51	16.37; 0.0002 *	0.38
Hip Abd	0.12; 0.73	2.49; 0.12	(0.08)	1.36; 0.25	(0.05)

Reported are F- and p-values; * mark significant results at $p < 0.05$, η_p^2= effect size partial Eta square.

Dependent t-tests showed no significant differences in the force values of the control group in pre-post comparison (trunk flexion t = -0.13, p = 0.90; trunk extension t = -1.33, p = 0.21; knee flexion t = 0.27, p = 0.80; knee extension t = -0.58, p = 0.58; hip adduction t = -1.05, p = 0.32; hip abduction t = -0.19, p = 0.85).

The t-tests for the force increase percentages between WB-EMS and control group found statistically significant differences with large effect sizes (Cohen's d > 0.8) for trunk flexion, knee flexion and extension, and hip adduction (Table 3).

CK values

For two of the players of the WB-EMS group, the CK values were >1,000 u/l already before the study started (1,752 and 1,701 u/l). The start of the intervention was delayed by a few days for these two until the values were below the threshold again. Both players absolved the same 10 training sessions afterwards as the other participants.

72 hours after the 1st WB-EMS session, the CK values exceeded the threshold for five players (mean 5,103.6 ± 3,283.1 u/l), and for one player, the CK value was still increased after the 2nd training session (1,140 u/l). For all other players, the value remained below the defined threshold (basic value: 199.3 ± 96.1 u/l; 72 h after the 1st training: 382.7 ± 168.7 u/l; 72 h after the 2nd training: 377.9 ± 159.2 u/l; 72h after the 8th training: 427.4 ± 154.1 u/l). The control group was sampled and showed mean values of 194.8 ± 35.9 u/l before intervention start up to a maximum of 426 u/l after week 8.

Discussion

To the authors' best knowledge, this study is the first that analyzes the effect of WB-EMS in youth elite soccer players. While we only could find small but not significant increases in strength in the leg, hip and trunk muscles in the control group performing athletic exercises for 20 min per week without additional WB-EMS application, the strength of the WB-EMS group improved significantly in 4 of the 6 muscle groups tested. It can therefore be supposed that an effective training stimulus was set by the WB-EMS application.

Training intensity and creatine kinase values

The electrodes applied for WB-EMS training cover large parts of the trunk, hip and leg musculature. The intensity control based on the RPE scale (range 6-7 = moderate-strong) ensured a sufficiently strong training stimulus. The blood CK values, which had significantly increased after the 1st training session, point to micro injuries in the muscle, possibly due to a high training load caused by the intensive contraction of large muscles (Meyer and Meister, 2011). These high CK values were gone after one week for all but one player. For that player, the high values had disappeared after two weeks. Literature knows about these bodily adjustments to WB-EMS training (Kemmler et al., 2018). Hughes et al. (2018) also found a normalization of stress-induced CK increases in female U17 footballers after 7 days. The top values during our study were still below values that might pose a potential health risk (Clarkson et al., 2006). Nevertheless, the very different courses of the CK values show that training monitoring by means of blood parameter control is recommended to avoid possible permanent muscular overload. It should be noted that CK release is obviously different for different genotypes, so there are also non-responders with low CK release after intensive muscular strain (Kindermann, 2016).

It always needs to be considered that especially young athletes tend to estimate their own training load incorrectly, also in combination with misled competitive thinking. The increased initial values before the WB-EMS intervention show that higher values (even without muscle pain) can be expected even under normal, performance-oriented competition conditions. This is also confirmed by a study by Kästner et al. (2015).

Strength increases

The strength increases identified in the WB-EMS group were all between 8.4% and 33.7% of the initial value. The control group did not exhibit any significant strength increases (all mean values were below 4%), although some players experienced quite remarkable individual increases in strength in several muscle groups. The training stimulus of the conventional athletic training (10 exercises without WB-EMS) was possibly low. Nevertheless, the participants in the control group indicated a strain of 6 to 7 on the RPE scale. Probably the once weekly exercise time of less than 10 minutes time-under-tension was too short to achieve significant increases in strength. Nevertheless, an increase in strength could still be observed in single individuals for single muscle groups as figure 3 shows. In addition, we hold the learning effects pertaining to the strength measurements also responsible for small strength increases in both groups. For some athletes, decreases of the initial value were measured. This might have been caused by inaccurate measurements or exhaustion of the participants due to previous sportive strain, although care was taken to ensure that the athletes did not engage in intensive sports activities on the day immediately before the tests. Nevertheless, accumulated muscular fatigue cannot be excluded during the 10 weeks of soccer and strength training. Since all measurements were performed by the same experienced examiner and the subjects were accustomed to the test procedure during the post-tests, adverse effects of inaccurate measurements should have been minimal.

Filipovic found strength gains of 8.5% (leg curl) to 15.1% (leg press) in adult soccer players through a seven-week additional EMS training (Filipovic et al., 2019). Our results for knee extensors and flexors are clearly higher, but our training intervention lasted 10 weeks in total and the training time-under-tension of about 5:30 min per session, with nine exercises that worked on the leg muscles, was also higher than for Filipovic (3 × 10 maximal squat jumps twice a week, stimulation time 2 minutes per session). In a mini-meta review of five studies of moderately trained young adults, Wirtz et al. found only slight increases in strength of the thigh muscles (Wirtz et al., 2019). However, they emphasize that exercise specificity and the participants' training status play an important role in the influence of superimposed WB-EMS training. The soccer players participating in our study were all accustomed to resistance training with submaximal loads, which initially makes the high increases seem unexpected. Nevertheless, in elite soccer players significant increases in strength were also reported in a further study of Filipovic et al. (2016), who found strength gains in leg muscles (leg press) of 16.8% (7 weeks, 14 sessions) and 22.4% (14 weeks, 28 sessions) in highly trained adult athletes. Time under tension in this study was only 4 minutes/week. Micke et al. (2018) compared dynamic training with a similar training with superimposed WB-EMS in a group of male sport students. They found significantly higher improvements in the WB-EMS group for maximum leg extension forces (+ 7.7%) and conclude that the combination of dynamic exercises and WB-EMS seems to be an effective method to improve leg strength (Micke et al., 2018). In non-soccer-specific cohorts, von Stengel and Kemmler (2018) found increases in leg/hip extensor and flexor strength of 14.7% and 23.2%, respectively, in non-athletic men <35 years after WB-EMS intervention.

Weissenfels et al. found increases in the strength of the trunk flexors after WB-EMS training in the order of 7% in low back pain patients (Weissenfels et al., 2019) and Ludwig et al. in untrained subjects of 15.0-17.1% (Ludwig et al., 2019). As already mentioned, we explain the significantly higher strength increases in our study with the healthy and active young subjects. For the trunk extension, Kemmler et al. report increases of about 10% in a review (Kemmler et al., 2018), which corresponds to the magnitude of the values found in our study. Weak trunk muscles are blamed for the development of postural deficiencies (Buchtelová et al., 2013; Kim et al., 2006). Since this in turn can lead to the development of back pain (Dolphens et al., 2012), improving trunk strength of young soccer players is not only reasonable from a sports motor point of view but also from a health point of view (Kim et al., 2015).

All in all, we can state that the superimposed WB-EMS training resulted in substantial increases in strength in four of the six muscle groups tested, which in some cases were many times greater than those achieved by conventional strength training alone. For example, nine of the WB-EMS users achieved an averaged strength increase of over 20%, one even 33%, while in the control group the greatest mean strength increase was 14% (see also figure 3). Particularly noteworthy are the mean strength increases of 20% in the knee flexors (see table 3). This is particularly interesting for professional (youth) soccer, as this muscle group is considered to be protective muscles of the knee joint and its strengthening can significantly reduce the risk of ACL rupture (Dai et al., 2012; Silvers and Mandelbaum, 2011). Considering the low expenditure of time of 20 minutes per week, WB-EMS training seems to be a time-saving but, from a training science point of view, highly effective supplement to youth strength training, if all safety aspects are kept in mind. Our results thus confirm the conclusions drawn by Filipovic et al. (2016) for adult soccer players.

After verbal feedback from the young subjects of our study, they perceived the WB-EMS training as a workout with a high motivation factor. We consider this to be worth reporting, as the motivation to carry out resistance training plays an important role in youth soccer.

Limitations

As a limitation, it must be noted that the initial values of muscle strength for trunk flexion differed clearly between the WB-EMS and control group, so that the large increase in flexion strength of the WB-EMS group during the intervention could also be interpreted as 'catching up' of the formerly weaker subjects. The intervention and control group were not homogeneous, since for logistical reasons no randomization could be carried out. Therefore, the different starting conditions might have influenced the result. Nevertheless, the absolute mean values after the 10-week WB-EMS intervention were clearly higher in this group than in the control group. As the study was carried out during the soccer season, the additional load of the weekly matches could be a confounding and disturbing factor.

The playing times of the players during the season were recorded in a club-operated database in accordance with the guidelines of the German Football Association (DFB) for youth academies, so that a comparison could be made retrospectively. Nevertheless, in a field study the playing times can never be exactly the same, and in soccer the running distances are also different depending on the playing position and playing style, so that these were possible confounding factors that may have influenced the results. As the time of play of the subjects studied was somewhat equal during the study period (see Table 1), this should not have had a strong influence on the results.

Likewise, the number of exercise repetitions was not the same between WB-EMS and CON, because in WB-EMS the timing of the movement was exactly predetermined and in CON so many repetitions were to be performed in the given time that the perceived load corresponded to RPE 6-7. However, this meant that the subjective strain was the same in both groups, which was the important criterion for training control for us.

During WB-EMS all muscles were always electrically stimulated at the same time. For example, during exercises that were primarily aimed at the leg muscles (e.g., counter movement jumps) the trunk muscles were also stimulated. Therefore, the time-under-tension of individual muscles between WB-EMS and CON is not exactly comparable. Nevertheless, such positive 'side effects' were actually intended, because in practice the strength of WB-EMS lies precisely in the parallel, simultaneous activation of many muscles.

In addition, one must keep in mind that since part of the exercises were performed dynamically in both groups, but the strength assessments were performed isometrically, the training effects may have been underestimated in our study.

It should also be noted that the results found in our study relate to male adolescent elite soccer players. They cannot simply be transferred to other groups of subjects.

Conclusion

A ten-week superimposed whole-body electromyostimulation training improves the muscle strength of certain leg, hip and trunk muscles in male adolescent elite soccer players to a greater extent than a pure athletic strength training of the same duration and in the same subjective strain range.

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Key points

- Superimposed Whole-Body Electromyostimulation is an effective training method and increases the strength of certain leg, hip and trunk muscles in adolescent soccer players.
- During a ten-week training, average increases in strength between 8 and 33% could be observed.

AUTHOR BIOGRAPHY

Oliver LUDWIG
Employment
Scientist and Lecturer at the Department of Sports Science, Technische Universität, Kaiserslautern, Germany
Degree
PhD (Human Biology)
Research interests
Biomechanics in sports, gait and posture
E-mail: oliver.ludwig@sowi.uni-kl.de

Joshua BERGER
Employment
Research assistant at the Department of Sports Science, Technische Universität, Kaiserslautern, Germany
Degree
MSc, PhD-Student (Sports Science)
Research interests
Sports performance diagnostics in competitive sports
E-mail: joshua.berger@sowi.uni-kl.de

Torsten SCHUH
Employment
Soccer athletics coach at the Youth Academy (NLZ) Saar, Elversberg, Germany
Degree
B.A. (Fitness Economics)
Research interests
Sports performance diagnostics
E-mail:
torsten.schuh@sv07elversberg.de

Marco BACKFISCH
Employment
Research assistant at the Department of Sports Science, Technische Universität Kaiserslautern, Germany
Degree
MSc, PhD-Student (Sports Science)
Research interests
Performance analysis in soccer
E-mail:
marco.backfisch@sowi.uni-kl.de

Stephan BECKER
Employment
Research assistant at the Department of Sports Science, Technische Universität Kaiserslautern, Germany
Degree
MSc, PhD-Student (Sports Science)
Research interests
Biomechanics in soccer
E-mail: stephan.becker@sowi.uni-kl.de

Michael FRÖHLICH
Employment
Full Professor at the Department of Sports Science, Technische Universität Kaiserslautern, Germany
Degree
Prof., PhD (Sports Science)
Research interests
Performance analysis, methods and methodology, evaluation research
E-mail:
michael.froehlich@sowi.uni-kl.de

✉ **Oliver Ludwig**
Department of Sports Science, Technische Universität Kaiserslautern, 67663 Kaiserslautern, Germany.