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Research article

Effects of an Impulse Frequency Dependent 10-Week Whole-body Electromyostimulation Training Program on Specific Sport Performance Parameters

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Abstract
The difference in the efficacy of altered stimulation parameters in whole-body-electromyostimulation (WB-EMS) training remains largely unexplored. However, higher impulse frequencies (>50 Hz) might be most adequate for strength gain. The aim of this study was to analyze potential differences in sports-related performance parameters after a 10-week WB-EMS training with different frequencies. A total of 51 untrained participants (24.9 ± 3.9 years, 174 ± 9 cm, 72.4 ± 16.4 kg, BMI 23.8 ± 4.1, body fat 24.7 ± 8.1 %) was randomly divided into three groups: one inactive control group (CON) and two training groups. They completed a 10-week WB-EMS program of 1.5 sessions/week, equal content but different stimulation frequencies (training with 20 Hz (T20) vs. training with 85 Hz (T85)). Before and after intervention, all participants completed jumping (Counter Movement Jump (CMJ), Squat Jump (SJ), Drop Jump (DJ)), sprinting (5m, 10m, 30m), and strength tests (isometric trunk flexion/extension). One-way ANOVA was applied to calculate parameter changes. Post-hoc least significant difference tests were performed to identify group differences. Significant differences were identified for CMJ (p = 0.007), SJ (p = 0.022), trunk flexion (p = 0.020) and extension (p=.013) with significant group differences between both training groups and CON (not between the two training groups T20 and T85). A 10-week WB-EMS training leads to significant improvements of jump and strength parameters in untrained participants. No differences could be detected between the frequencies. Therefore, both stimulation frequencies can be regarded as adequate for increasing specific sport performance parameters. Further aspects as regeneration or long term effects by the use of different frequencies still need to be clarified.

Key words: WB-EMS, muscle fiber, jumping, sprinting, performance diagnostics.

Introduction

For many years, electromyostimulation (EMS) training has been established as a proven type of training in the areas of rehabilitation and clinical intervention. After injuries, it enables athletes to reduce a decrease in performance and to support the reconstruction of muscles, as well as to create new stimuli in training routine (Seyri and Maffiuletti, 2011). A particular focus is placed on whole-body-EMS (WB-EMS) training: electrodes are attached to the skin all over the body (upper arms, gluteus, chest, abdomen, lower and upper back, thighs, shoulder) and stimulate the muscles underneath them via an externally applied stimulus. The stimulation of the motor units results in signal transduction into the muscle and thus to involuntary muscle contraction. Maximum strength increase is paramount in EMS. In a review, Filipovic et al. (2012) reported that a 3-to-6-week EMS training can result in maximum increases of up to 58.8 % in isometric and 79.5 % in dynamic maximum strength.

Planning and implementing WB-EMS training, however, need to take into account many parameters. For example impulse duration and rest intervals, impulse width, number of training units per week, regeneration times, fatigue, dynamic or static exercises have an essential impact on the effectiveness of WB-EMS (Filipovic et al., 2011; 2012; 2016). Especially the exertion intensity significantly influences the strength development of the target muscles in WB-EMS training (Binder-Macleod and McDermond, 1992). A linear interrelationship seems to exist between impulse intensity and strength development (Maffiuletti, 2010). There is also a positive relationship between a muscle's strength development during training and the resulting strength increases (Binder-Macleod and McDermond, 1992). This means that impulse intensity plays an essential role in terms of strength increase through EMS training. A further factor deemed important due to the associated muscular stimulation method is the stimulation frequency in Hertz (Hz) applied during training. Frequency is the number of impulses per second that reach the muscle via the electrode attached to the skin and trigger a contraction (Bossert et al., 2006; Wenk, 2011). An interrelationship was identified between the frequency applied and the strength development in the muscle (Binder-Macleod and McDermond, 1992). To date, numerous studies have dealt with the application of different frequencies under varied conditions (Amaro-Gahete et al., 2018b; Filipovic et al., 2011; Moreno-Aranda and Seireg, 1981). In the past, the variability of training protocols and experimental implementation often result in difficulties to compare the individual analyses. Meanwhile, a more standardized use of stimulation parameters and protocols over the last years enables a better comparability between different studies (Filipovic et al., 2011; Selkowitz, 1989). Thestimulation frequency in WB-EMS training usually ranges between 20 and 150 Hz (Vatter et al., 2016; Vogelmann, 2013). There is no consensus on the existence of an "optimal" frequency range. In their review, Filipovic et al. state that frequencies around 76 Hz lead to an optimal strength development of the musculature (Filipovic et al., 2011). Frequencies below 50 Hz have only been analyzed to a limited extent so far.

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Force development during WB-EMS training positively correlates to strength increases observed in the target muscles, with the optimal choice of protocol having a significant effect on training success (Binder-Macleod and McDermond, 1992). At a frequency of 5 Hz, for example, the muscles completely relax between the contractions, whereas the individual impulses sum up with increasing frequency. This means that the muscle can no longer relax completely with increasing frequency. Summing the individual impulses results in a higher strength development in the muscles and a so-called unfused (incomplete) or fused (complete) tetanic contraction (tetanus). Furthermore, the impulse frequency seems to correlate directly with force development (Glaviano and Saliba, 2016). Bigland-Ritchie et al. (1979) were able to show that muscular stimulation at a frequency of 20 Hz generates only 65 % of the strength compared to stimulation at 50-80 Hz. Kramme (2007) attributes an optimal faradic stimulation of striated musculature to frequencies of 50 Hz (Kramme, 2007), adue to fused tetanus (Wenk, 2011). High frequencies seem to lead to faster neuromuscular fatigue and can therefore result in an earlier decrease of performance (Bigland-Ritchie et al., 1979) because the organism is subject to higher exertion (Glaviano and Saliba, 2016; Gondin et al., 2010). Apart from the strength development generated by the different frequencies, specific frequencies are attributed with an increased stimulation of specific muscle fiber types. Frequencies of 20-40 Hz mostly cause a stimulation of the slow type-I fibers (slow-twitch, ST), whereas stimulation between 50 and 120 Hz rather activate the faster type-II muscle fibers (fast-twitch, FT) (Frenkel et al., 2004; Vogelmann, 2013). For this reason, the use of an "optimal" stimulation frequency has not been unambiguously clarified. Depending on the author, the modes of action and frequency ranges and, accordingly, the applicability differs.

In today's WB-EMS training, it seems to be generally agreed that a stimulation frequency around 85 Hz represents an effective value wherefore it is usually applied most of the time (Berger et al., 2019; Brocherie et al., 2005; Filipovic et al., 2011; Micke et al., 2018). Nevertheless, the authors have no knowledge of scientific evidence pertaining to the direct comparison of the 20 Hz and 85 Hz stimulation frequencies and their impact on specific performance parameters. Therefore, the objective of this study was to determine: a) whether a 10-week EMS training might have an impact on specific sport performance parameters, and b) if any difference might occur between a control group (CON), a training group exercising at 20 Hz (T20), and a group exercising at 85 Hz (T85), under otherwise identical stimulation conditions.

Methods

The study was conducted using a randomized controlled trial (RCT). The participants were randomly assigned to one of the three groups (two training groups, one control group; groups were assigned by drawing cards).The training groups completed a 10-week training phase with 1.5 training units per week (Kemmler et al., 2016a; Kemmler et al., 2016b). They only differed due to the stimulation frequency used in WB-EMS (20 Hz or 85 Hz), all other contents and stimulation parameters were identical. CON was instructed not to engage in exercise during the period. Performance parameters (jump-, sprint- and strength parameters) were measured both before and after the intervention. This study design enabled us to compare within and between group differences to identify possible differences in the increase in performance due to the impulse frequency used.

Participants

A total of 58 persons participated in the study. Seven people did not complete the 10-week WB-EMS training or the final diagnostics, they were excluded from the data analysis (Figure 1) (Schulz et al., 2010). Thus, a total of 51 participants were included in the analysis. The anthropometric data are shown in Table 1. Inclusion criteria were an age between 18 and 40 years, < 1h/week of athletic activity, being new to WB-EMS training, and no internal and orthopedic limitations. Before the study began, the participants were informed about relative and absolute contraindications, and potential exclusion criteria were verified (Kemmler et al., 2016a; Vatter et al., 2016). The participants gave their written consent. The study was approved by the ethics commission responsible (ref. no. 02/17) and was conducted based on the Declaration of Helsinki (World Medical Association, 2013).

Procedures

Anthropometric and performance parameters were recorded during both pre- and post-tests. Each participant performed a jump session of a total of three different jumps: counter movement jump (CMJ), squat jump (SJ), and drop jump (DJ). For all three types of jumps, proper arm positioning (hands on hips) and leg extension during the jump (no flexing to extend the jump phase, i.e., no skewing the height of the jump) were ensured. The participants could self select how deep they lowered their body (not more than 90° knee angle). To exclude an eccentric movement in the SJ, the participants had to remain in the reversal point for 2 seconds (Faude et al., 2010). Jump heights and contact times were measured by means of the Optojump Next optical measurement system (Microgate, Bolzano, Italy). For the evaluation of the DJ, a reactive strength index was calculated based on jump height divided by ground contact time.

Linear sprint diagnostics were conducted using the Witty Kit photoelectric sensor system (Microgate, Bolzano, Italy), measuring the linear sprint times over the 5 m, 10 m, and 30 m distances. The start was performed without a signal from a standing position 50 cm away from the first photoelectric sensor. The participants started at their own discretion without the influence of response time (Faude et al., 2010).

Static trunk extension and flexion (isometric strength tests) were measured by Back Check 607 (Dr. Wolff GmbH, Arnsberg, Germany). This required the participants to stand with dangling arms and slightly bent knee joints. They were fixated at the iliac crest area by one dorsal and one ventral pad in the sagittal plane. For measurement recording purposes, two pads with force transducers were placed without pressure at the sternum

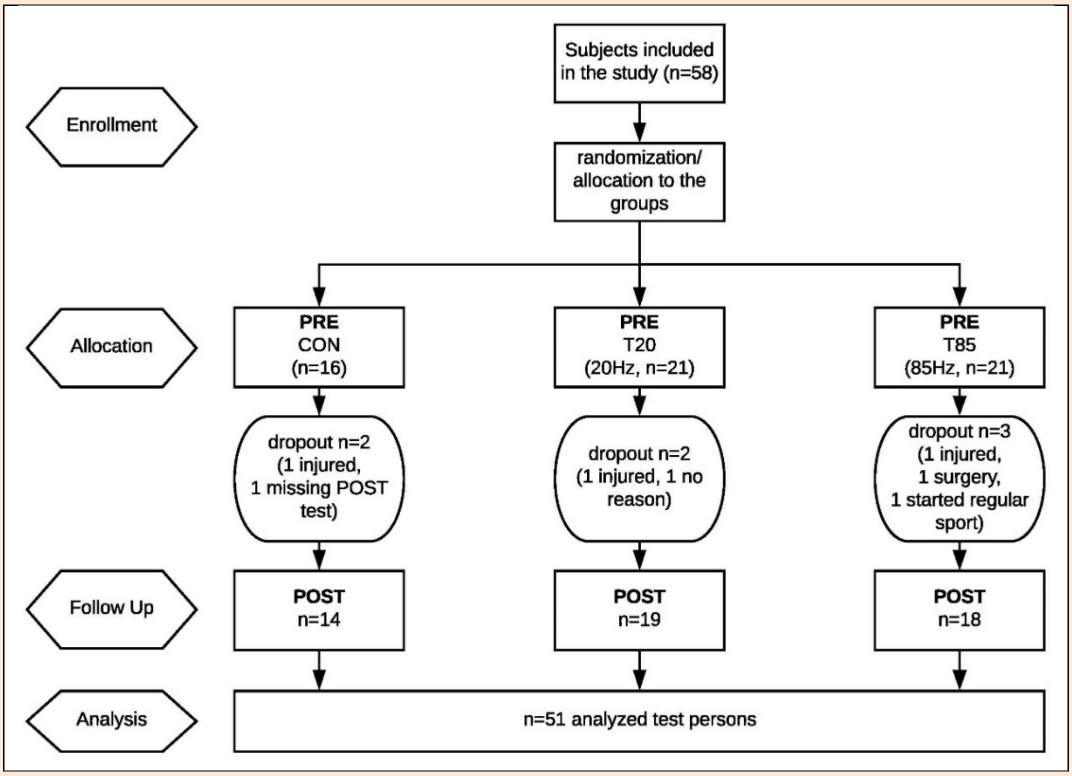

Figure 1. Flow of participants.

Table 1. Anthropometric data of the different groups (control group (CON), 20 Hz training group (T20) and 85 Hz training group (T85)). Data are means ± SD.

Parameters	CON (n = 14)	T20 (n = 19)	T85 (n = 18)	Overall (n = 51)
Age [Years]	25.6 ± 2.8	24.8 ± 4.0	24.5 ± 4.4	24.9 ± 3.9
Height [cm]	168.2 ± 7.1	174.3 ± 7.9	176.7 ± 9.7	174.0 ± 8.9
Weight [kg]	67.1 ± 19.9	74 ± 16.3	73.3 ± 15.1	72.4 ± 16.4
BMI [kg/m^2]	23.5 ± 5.9	24.1 ± 3.8	23.9 ± 3.7	23.8 ± 4.1
Body Fat [%]	27.3 ± 7.8	25.8 ± 8.1	21.7 ± 8.1	24.7 ± 8.1

and between the shoulder blades. The maximum strength was recorded in both directions. The tests were performed three times (30 seconds rest between the tests) with the maximum value being used for analysis (Weissenfels et al., 2019).

All participants were randomly assigned to one of the two training groups or to the control group. Participants and the investigators were not informed about the assignment at any time during the study in order to achieve double blinding. In WB-EMS, the training groups differed only in the stimulation frequencies applied. Participants performed a familiarization session before training began. This session lasted 12 minutes and included a low-intensity impulse familiarization to prepare for the upcoming training sessions and to get to know the WB-EMS training better (Kemmler et al., 2016a). The10-week training included a total of 15 WB-EMS sessions. Participants alternatingly exercised once or twice a week, so that an average of 1.5 training sessions was performed per week and overexertion was avoided (Berger et al., 2017; Kemmler et al., 2016a; 2018). All training units were personalized and featured one trainer for two participants, this ensured optimal support and immediate care and supervision. The training times were performed at the same time of the day to avoid fluctuating diurnal performances. Before each training session, a brief anamnesis questionnaire on the current health condition was completed in order to exclude spontaneously occurring contraindications. This included aspects such as sudden nausea, lack of sleep, physical exertion within the previous 24 hours, or recent consumption of alcohol, drugs, or pain medication. In case of present contraindications, the training was not performed. The participants were instructed not to perform the training with a completely empty stomach, and to ensure sufficient intake of liquids (at least 500 ml within the last hour) in order to prevent circulatory problems and performance losses (Kemmler et al., 2016a).

The other parameters were based on the standard experimental parameters of WB-EMS application: Impulse width 350 µs, duty cycle 50 % (4 s impulse, 4 s break), bipolar impulse without impulse increase (square pulse) during an overall training time of 20 minutes (Kemmler et al., 2018; Vogelmann, 2013). Intensity was controlled by means of a rating of perceived exertion (RPE) scale (0=no exertion, 10=maximum exertion), which is a subjective method of determining intensity that is commonly used in practice (Amaro-Gahete et al., 2018a; 2018b; Kemmler et al., 2018). Participants were instructed to exercise at a perceived intensity between 6 and 7 and not to exceed this value in order to avoid overexertion (Borg and Kaijser, 2006). It was also ensured that the selected intensity did not have any negative effect on the range of motion (ROM) during the movements to allow a full movement amplitude during the exercises. The intensity was individually increased through the RPE scale and targeted specific muscle groups in order to ensure adequate exertion. WB-EMS training was performed using the Miha Bodytec 2 WB-EMS device (Miha Bodytec, Augsburg, Germany), which is a stationary system including a control panel for impulse control and a monitor to control the exercises via an integrated avatar. The electrodes were connected to the WB-EMS device via an electrode vest and additional belts. This enabled simultaneous stimulation of 16 body regions (including upper arms, gluteus, chest, abdomen, lower and upper back, thighs, shoulder) (Kemmler et al., 2012). Each electrode could be individually controlled.

The exercises were selected based on the integrated Miha Bodytec exercise catalog. Therefore, the training programs applied represented training content typical for WB-EMS studios. Exercise selection especially focused on long sequences of basic exercises in order to simultaneously stimulate as many muscle groups as possible (Figures 2a-2i).

The participants were instructed to maintain a pretension in their muscles before the impulse was applied in order to avoid unpreparedness and thus potential negative reactions. It was also ensured that the test persons completely mastered the training exercises before the intensity and thus complexity of the exercise was increased.

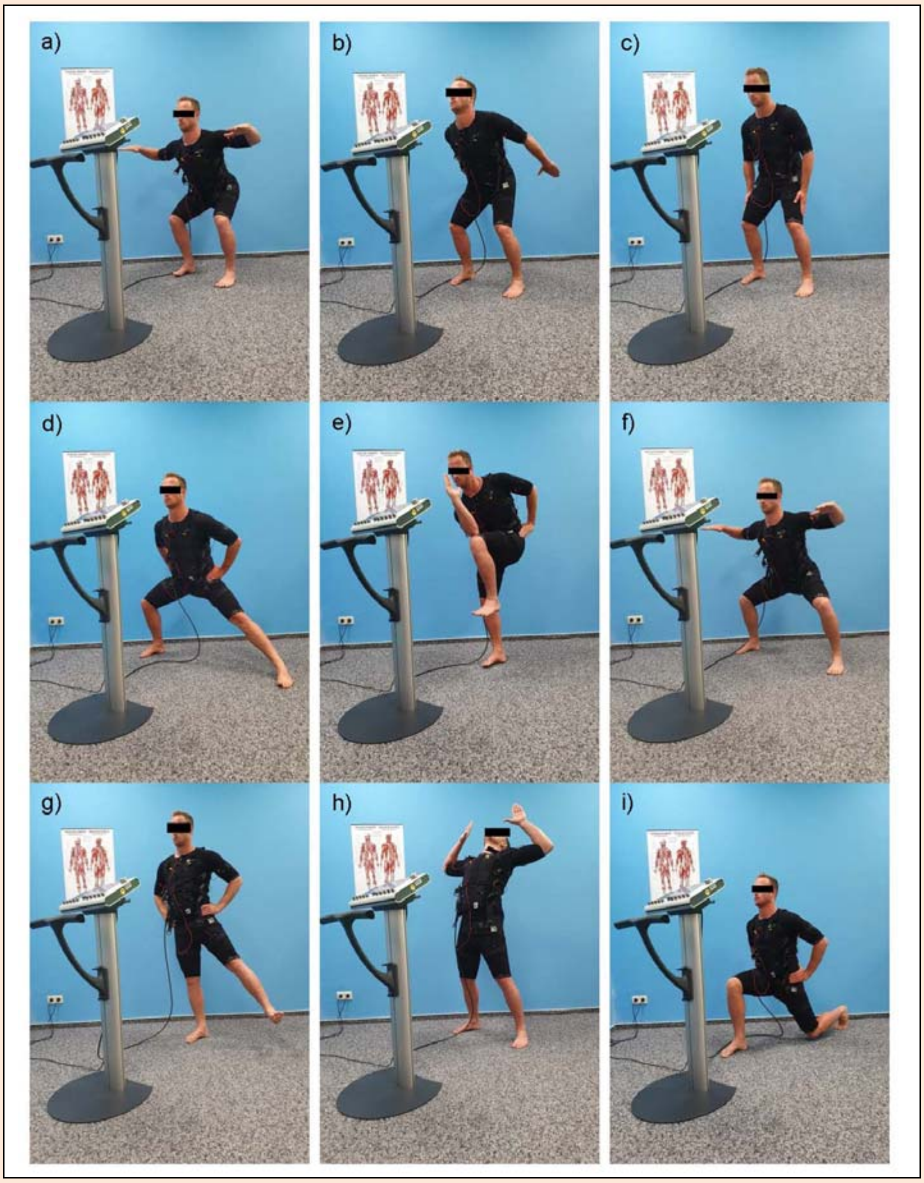

Figure 2. Selected exercises in the WB-EMS training program. a) dynamic knee flexion (15 repetitions), **b)** dynamic trunk flexion (12 repetitions), **c)** static knee presses against own resistance (12 repetitions), **d)** dynamic side lunge, left and right (10 repetitions each), **e)** dynamic crunches, diagonal, left and right (10 repetitions each), **f)** dynamic knee flexion, wide stand (15 repetitions), **g)** dynamic one-leg stand with lifting one leg, left and right (10 repetitions each), **h)** dynamic overextension of the trunk (12 repetitions), **i)** static forward lunge, left and right (12 repetitions each).

Statistical analyses

All statistical analyses were conducted using SPSS Statistics (IBM, Version 25.0, Chicago, IL, USA) setting level of significance at $p < 0.05$. All values are given as means ± standard deviation (SD). Since ANOVA is known to be robust against infringements of the normal distribution and all variances were homogeneous (Levene test) it was applied every time (Field, 2009; Schmider et al., 2010). Therefore, ANOVA was used to examine the effect of group on CMJ_{DELTA} ($CMJ_{POST} - CMJ_{PRE} = CMJ_{DELTA}$) and all other parameters of the jump tests (SJ, DJ), sprint tests (5 m time, 10 m time, 30 m time) and strength tests (trunk flexion, trunk extension). Furthermore, all confidence intervals were calculated and stated. To estimate interaction effect sizes, partial eta squared (η_p^2) was computed with $\eta_p^2 \geq 0.01$ for small, ≥ 0.059 for medium, and ≥ 0.138 for large effects (Cohen, 1988; Levine and Hullett, 2002). A median split was applied to check whether the parameter improvements showed differences between the two training groups (T20, T85).

Results

Jump parameters

All jump diagnostics values and the difference between PRE and POST (Delta, Δ) including the percentage changes are illustrated in Table 2. The CMJ exhibited significant changes between the groups ($F(2, 47) = 5.54$, $p = 0.007$, $\eta_p^2 = 0.191$), differences in pairs between CON and T20 ($p = 0.002$) as well as between CON and T85 ($p = 0.013$). The SJ also exhibited significant changes between the groups ($F(2, 47) = 4.15$, $p = 0.022$, $\eta_p^2 = 0.150$), differences in pairs between CON and T20 ($p = 0.018$) and between CON and T85 ($p = 0.01$). No significant differences were identified for the DJ ($F(2, 46) = 2.38$, $p = 0.104$, $\eta_p^2 = 0.094$). No difference was found in the extent of improvement for the jump parameters between the T20 and T85 training groups based on an additional median split. Both groups reacted in similar ratios to the training interventions. Figure 3a-c shows the jump parameter boxplots.

Sprint parameters

Table 2 also shows the sprint diagnostics values. There were no significant changes in the sprint results at 5 m ($F(2, 47) = 0.30$, $p = 0.744$, $\eta_p^2 = 0.012$), 10 m ($F(2, 47) = 0.64$, $p = 0.534$, $\eta_p^2 = 0.026$), and 30 m ($F(2, 47) = 0.68$, $p = 0.511$, $\eta_p^2 = 0.028$). Figure 3 d-f shows the sprint parameter boxplots.

Strength parameters

Trunk flexion exhibited significant changes between the groups ($F(2, 48) = 4.24$, $p = 0.020$, $\eta_p^2 = 0.150$) as well as differences in pairs between CON and T20 ($p = 0.042$), and between CON and T85 ($p = 0.006$). Trunk extension also exhibited significant changes between the groups $F(2, 48) = 4.75$, $p = 0.013$, $\eta_p^2 = 0.162$) as well as differences in pairs between CON and T20 (p=.003), and between CON and T85 ($p = 0.048$). No distribution difference was found for the strength parameters between the T20 and T85 training groups based on an additional median split. Both groups reacted in similar ratios to the training interventions. Figure 3 g-h shows the strength parameter boxplots.

Table 2. Descriptives, ANOVA and multiple comparisons of all parameters. Values are presented as means (± SD).

Outcome parameter	Group	PRE	POST	Delta PRE-POST	% Delta PRE-POST	Univariate ANOVA [a] p	Univariate ANOVA [a] η_p^2	Multiple comparison (LSD) [b] Groups	Multiple comparison (LSD) [b] p
Jump tests	**CON**	24.6 ± 6.2	24.5 ± 5.7	- 0.3 ± 2.3	- 0.4 %			CON vs. T20	0.002**
CMJ [cm]	**T20**	25.4 ± 9.0	27.8 ± 7.6	2.4 ± 2.2	+ 9.5 %	0.007**	0.191	CON vs. T85	0.013*
	T85	26.5 ± 8.1	28.4 ± 7.3	1.9 ± 2.3	+ 9.5 %			T20 vs. T85	0.456
SJ [cm]	**CON**	23.2 ± 6.0	23.5 ± 6.0	0.3 ± 1.4	+ 1.3 %			CON vs. T20	0.018*
	T20	23.9 ± 8.5	26.2 ± 7.3	2.4 ± 2.2	+ 9.6 %	0.022*	0.150	CON vs. T85	0.010*
	T85	24.3 ± 7.0	26.8 ± 6.4	2.5 ± 2.4	+ 10.3 %			T20 vs. T85	0.832
DJ [Index]	**CON**	87.4 ± 34.1	91.1 ± 32.3	0.1 ± 19.2	+ 4.2 %				
	T20	97.4 ± 37.2	110.1 ± 35.4	12.7 ± 18.7	+ 13.0 %	0.104	0.094		
	T85	101.5 ± 33.9	115.8 ± 32.7	14.3 ± 18.5	+ 14.1 %				
Sprint tests	**CON**	1.15 ± 0.09	1.15 ± 0.05	- 0.01 ± 0.08	± 0.0 %				
5 m [s]	**T20**	1.15 ± 0.09	1.13 ± 0.08	- 0.02 ± 0.06	- 1.7 %	0.744	0.012		
	T85	1.11 ± 0.11	1.11 ± 0.08	0.00 ± 0.09	± 0.0 %				
10 m [s]	**CON**	2.07 ± 0.16	2.04 ± 0.10	- 0.04 ± 0.09	- 1.5 %				
	T20	2.03 ± 0.17	2.01 ± 0.17	- 0.02 ± 0.08	- 1.0 %	0.543	0.026		
	T85	1.94 ± 0.17	1.94 ± 0.14	0.00 ± 0.12	± 0.0 %				
30 m [s]	**CON**	5.35 ± 0.52	5.34 ± 0.44	- 0.05 ± 0.18	- 0.2 %				
	T20	5.15 ± 0.59	5.06 ± 0.57	- 0.08 ± 0.21	- 1.8 %	0.511	0.028		
	T85	4,88 ± 0.47	4.87 ± 0.44	- 0.01 ± 0.16	- 0.2 %				
Strength tests	**CON**	43.3 ± 18.6	45.7 ± 20.1	2.0 ± 6.3	+ 5.5 %			CON vs. T20	0.042*
Trunk	**T20**	49.1 ± 17.2	56.4 ± 19.3	7.1 ± 5.9	+ 14.9 %	0.020*	0.150	CON vs. T85	0.006**
Flexion [kg]	**T85**	53.3 ± 20.1	62.4 ± 24.6	9.1 ± 7.9	+ 17.1 %			T20 vs. T85	0.388
Trunk	**CON**	58.5 ± 20.6	62.7 ± 20.5	3.9 ± 5.5	+ 7.1 %			CON vs. T20	0.003**
Extension [kg]	**T20**	60.3 ± 17.9	72.9 ± 18.1	12.6 ± 9.1	+ 20.9 %	0.013*	0.162	CON vs. T85	0.048*
	T85	68.2 ± 23.0	77.9 ± 25.7	9.6 ± 8.4	+ 14.2 %			T20 vs. T85	0.184

[a] Results of the univariate ANOVA of the Delta values; [b] Group comparisons: control group (CON), 20 Hz training group (T20), 85 Hz training group (T85); * p < 0.05, **p < 0.0.1

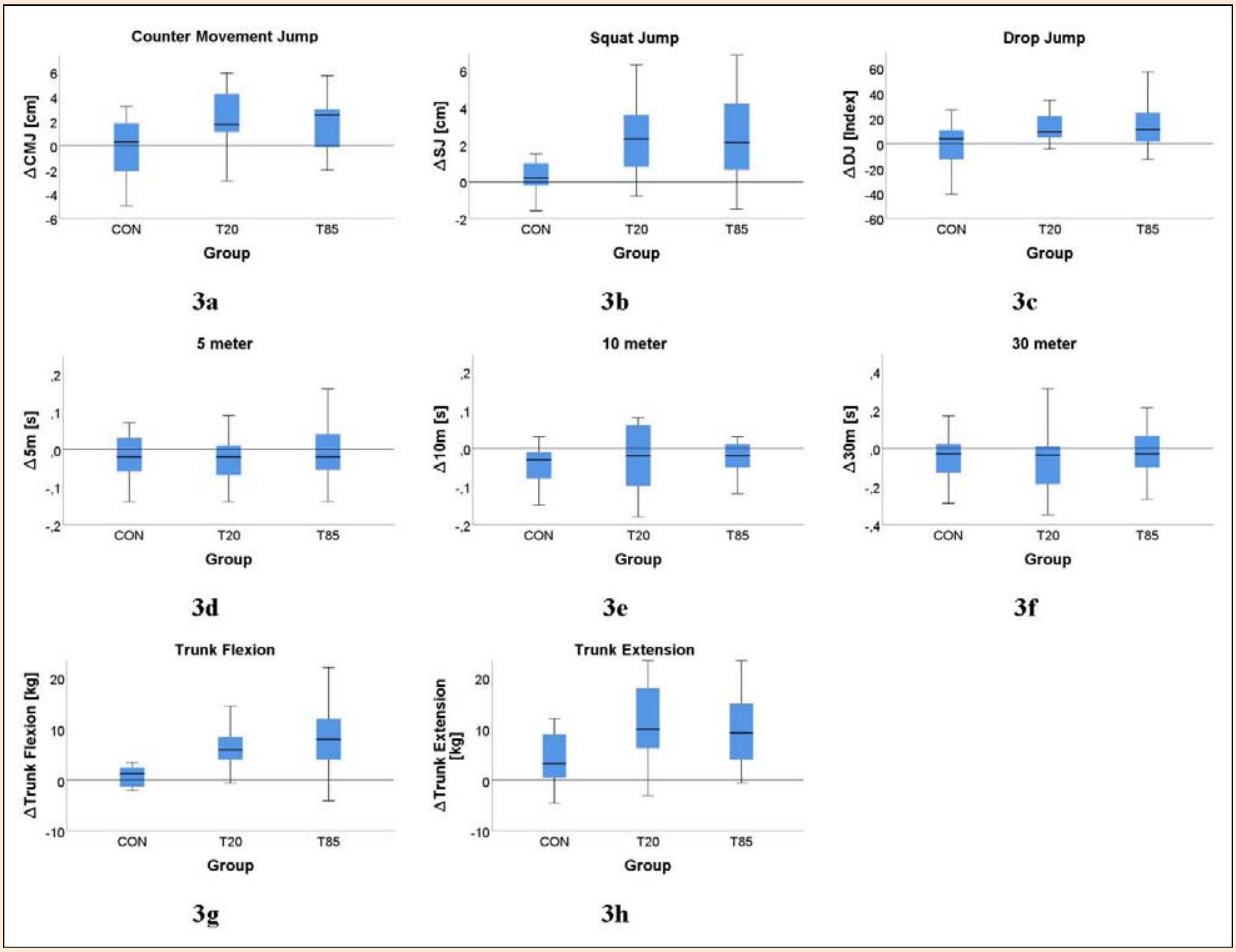

Figure 3. Boxplots of all measured parameter (Abbreviations: control group (CON), 20 Hz training group (T20) and 85 Hz training group (T85)).

Discussion

In many areas, WB-EMS training is considered to be an intense, effective, and time-saving training. The current state of research pertaining to the stimulation frequencies applied is rather insufficient, though (Filipovic et al., 2011). Therefore, the objective of this study was to analyze the effects of a frequency-based, 10-week WB-EMS training on selected performance parameters, focusing on potential differences between the stimulation frequencies applied (20 Hz and 85 Hz). The main findings of this analysis were a) 10-week WB-EMS training has a positive effect on performance increase in CMJ, SJ, trunk flexion, and trunk extension; and b) differences in performance increase were identified between the control group and the training groups. However, no frequency-based difference was identified for the performance increase of the training groups relative to one another under otherwise identical stimulation conditions. This is why the original assumption of different performance increases of T20 and T85 through the application of different frequencies cannot be confirmed (Frenkel et al., 2004; Gregory and Bickel, 2005).

Jump parameters

In previous analyses, EMS has shown to increase jump parameters as CMJ (+25.2 %), SJ (+21.4 %) and DJ (+12 %) significantly (Filipovic et al., 2012). However, these performance increases seem to depend largely on the stimulation and training protocols used. Increases of 25.2 % in the CMJ were observed in female track and field athletes. However, a parallel pre-season strength/EMS training was performed over a period of 6 weeks, therefore the results cannot be clearly attributed to the EMS training (Willoughby and Simpson, 1998).

An increase of 21.4 % in SJ was achieved by a combined local EMS and plyometric jump training for volleyball players, which shows the same problem as in the previous study due to the mixing of the training forms (Maffiuletti et al., 2002). Looking at physically active test persons without a high-performance athletic background and parallel training, the performance increases resulting from a combined EMS training are 7.3 % for CMJ and 7.5 % for SJ (Herrero et al., 2006). This is in accordance with our results in this study (CMJ 9.5 %, SJ 10.3 %).

Filipovic et al. (2016) analyzed the impact of a 14-week WB-EMS training on strength, sprint speed, jump height, and kicking capacity in 22 soccer players. The WB-EMS sessions were performed twice a week (a total of 28 units) in addition to the regular training (6-7 times per week). Improvements were observed for SJ (8.0%) and also in the sprint time at the 5 m distance (2.9 %). However, these results were not confirmed by our findings. In addition to the different participant characteristics (soccer players), a potential reason for this discrepancy could be the higher number of training sessions performed during the study of Filipovic (14 weeks, 28 units). After 7 weeks of treatment (14 units, similar to our investigation) improvements of only 4.2 % for SJ and 1.8 % for 10 m time were identified, but none for the 5 m distance. In contrast to the time measured for the 5 m distance after 14 weeks, the improvements in the 10 m sprint were not confirmed (Filipovic et al., 2016). Amaro-Gahete et al. (2018b) also analyzed a performance increase after a 6-week WB-EMS application (1 unit per week) using 6 recreational runners. They were able to identify improvements of 4.4 % for CMJ and 8.4 % in the Abalakov jump (CMJ with free-swinging arms). They believe that these improvements are due to neuromuscular adjustments, improved intermuscular coordination, or changes in muscle size(Amaro-Gahete et al., 2018b).

In summary, the performance increases of CMJ and SJ are similar or higher (CMJ 9.5 %, SJ 10.3 %) than those described in literature. The lack of improvement in the DJ may possibly be due to the highly coordinative requirements of this type of jump. Previous studies recorded improvements in the DJ height of up 12 % (Filipovic et al., 2012) in very active athletes. However, due to the above-mentioned requirements the strength increases may not be transferable to less trained persons.

Sprint parameters

Not only the jump parameters can benefit from a strength increase in the target musculature, but also the sprint speed (Filipovic et al., 2016). The current state of research is not very comprehensive in this case, either. WB-EMS is rather neglected over locally applied EMS. Brocherie et al. (2005) analyzed the impact of 9 local EMS units on the m. quadriceps femoris with a duration of 12 minutes each (85 Hz, 250 µs; 4 s impulse duration; 20 s impulse break) in 17 ice hockey players. They found a resulting improvement of the 10 m skate sprint time of 4.8 % (Brocherie et al., 2005). Through local stimulation of the m. quadriceps femoris of 40 test persons with a duration of 34 minutes each for 16 units (120 Hz; 400 µs; 3s impulse duration; 30 s impulse break), Herrero et al. (2006) achieved a significant improvement of 2.4 % in the 20 m distance sprint time. The problem of the comparability of study protocols is also shown here, as the previous studies have used a local EMS application, whereas we have applied WB-EMS. We could not detect any performance gains over the tested distances. A possible reason could be the focus on the local EMS application in comparison to a WB-EMS application, because the body is exposed to much greater stress and the isolated local EMS training could be more effective in direct relation to the sprint values and the motor implementation of the generated strength gains.

Comparable to our study is the intervention of Filipovic et al. (2016). They achieved an improvement of 2.9 % in the 5 m sprint time after a 14-week WB-EMS training applying similar stimulation parameters as we did in our tests. Performance increases over distances of 10 m, 20 m and 30 m did not occur, just as in our study. The improvement in the 5 m sprint time could also be due to multiple soccer training. Furthermore, in contrast to the untrained persons who participated in our study, the test persons consisted of high-performance athletes, who are better at transferring potential strength gains to a sport-specific movement. Sprints are characterized to a large extend by technical components such as a maximum speed of cyclic movements. Those technical influences on the sprinting time could be a possible reason for the lack of improvement here, even if there is an increase in force or an improvement of the vertical jump height.

Strength parameters

The large-area electrodes applied during WB-EMS training stimulated, among others, the rectus abdominis muscle (trunk flexion), the erector spinae (pars lumbalis and thoracalis) muscle, and the multifidii muscles (trunk extension). According to our training protocol we can assume an adequate training stimulus and therefore muscle strengthening during the 10-week training period (Ng and Richardson, 1994).

Previous studies have already shown positive effects of several weeks of WB-EMS training on strength parameters. A training session once a week over a period of 12 weeks showed improvements of 14.6 % - 15.6 % for the trunk extension and 15.3 % - 17.6 % for the trunk flexion (Weissenfels et al., 2018; Weissenfels et al., 2019). During a 16-week training phase with 1.5 training units per week, improvements of 11.6 % were achieved for the back extensors (Kemmler et al., 2016b; 2018). These findings are congruent with our results despite deviations in the intervention duration. We were able to demonstrate significant improvements in isometric forces of trunk flexion and extension in both training groups with high effect sizes ($\eta^2 > 0.15$). We observed percentage improvements between 14.2 % and 20.9 % for back extension and between 14.9 % and 17.1 % for back flexion in the training groups during the 10-week training program. In conclusion, we were able to generate similar strength gains as in the existing literature with the same or slightly increased training effort (1.5 sessions/ week) over a shorter period of time.

However, there were no significant differences between the two training groups. Both 20 Hz and 85 Hz therefore seem to be adequate stimulation frequencies. Nevertheless, T20 showed the greatest increases in trunk extension strength. The back muscles (especially the M. erector spinae), which are responsible for posture stabilization, consist mainly of slow type-I fibers (men: 62.0 % ± 9.3 %, women: 67.8 % ± 10.5 %). In contrast, T85 exhibited the greatest increase in trunk flexion strength. On average, the associated muscle groups consist of a slightly higher proportion of faster type-II fibers (type I: 46.1 %, type II: 53.9 % (Johnson et al., 1973)). These compositions potentially explain the different responses to the stimulation frequencies applied.

Stimulation protocol

The stimulation protocols applied as well as the contents of the described studies about performance increases of diverse parameters vary strongly and are therefore not easily comparable. According to the authors' knowledge, this is the only analysis based on a WB-EMS training applying different frequencies and a device-specific training program over a period of multiple weeks with healthy, untrained test persons. Differences in performance increase among the groups due to the application of different stimulation frequencies and otherwise identical stimulation protocols have not been reported. A potential explanation lies in the contraction behavior of the stimulated muscles and their response to an involuntary, externally applied stimulus. In voluntary muscle contractions, the motor units (MU) are usually stimulated according to their size, i.e., from the small to the large MU. Small, slow MU are responsible for stimulating slower type-I fibers (slow-twitch, ST) and faster, larger MU for the contraction of faster type-II fibers (fast-twitch, FT) (Enoka, 2002). In WB-EMS training, a conversion of the recruiting pattern may take place so that a stimulation of the faster type-II fibers occurs early on. The reason for this phenomenon is that larger MU have larger axons, which have a lower stimulus threshold than smaller axons as they occur in smaller MU (Enoka, 2002). Moreover, larger MU are often located closer to the skin surface which may result in an earlier stimulation (Fehr, 2011; Garnett and Stephens, 1981). Concerning EMS training, Gregory and Bickel (2005) suggest that non-selective synchronous recruiting of MU occurs , which, by implication, means simultaneous stimulation of both muscle fiber types during low strength production (Seyri and Maffiuletti, 2011). Therefore, a predominant stimulation of a specific muscle fiber type depending on the frequency selected would not be determinable. Moreover, the force-frequency relationship (FFR) may represent a relevant influencing factor pertaining to the stimulation frequency to be selected. The FFR defines the interrelationship between strength production and selected stimulation frequency during an EMS application. The force produced in the muscle increases with increasing frequency as the individual impulses accumulate, until a maximum summation on a force plateau occurs (Binder-Macleod and McDermond, 1992). For frequencies < 5 Hz, Binder-Macleod and McDermond (1992) were able to show a complete relaxation of the m. quadriceps femoris between the individual impulses and a summation to fused tetanus with increasing frequency. A growing exertion intensity caused by an increased strength production may have a positive association with the strength increases generated in EMS training, which would support an increase of the stimulation frequency applied (Binder-Macleod and McDermond, 1992; Selkowitz, 1989). However, strength production increases caused by stimulation frequency increases also lead to increased metabolic demands of the muscle (energy requirement, phosphocreatine ratio values, pH level) and can therefore not be maintained for an unlimited time (Glaviano and Saliba, 2016). Accordingly, fatigue of the target musculature is linked to stimulation. Therefore, it seems to be necessary to reduce the stimulation frequency in order to ensure sufficiently long exertion without causing too much fatigue and potential muscle damage. This means that a frequency needs to be as low as possible to ensure maximum strength production at a minimum rate of fatigue (Binder-Macleod and McDermond, 1992; Delitto and Snyder-Mackler, 1990). For example, Glaviano et al. (2016) describe an optimal stimulation frequency of 30-50 Hz and explain the application of these low frequencies with the possibility to increase the impulse width to 400-600 µs in order to achieve optimal strength production at a minimum rate of fatigue and muscle damage (Glaviano and Saliba, 2016). Binder-Macleod and McDermond (1992) increase this assumption to a frequency of 60 Hz. Based on this fact, Dreibati et al. (2010) analyzed three different stimulation frequencies (20, 50, and 100 Hz; impulse width 300 µs) in terms of the resulting fatigue respectively production of the maximal voluntary contraction (MVC) of the m. quadriceps femoris at the end of a 20-minute EMS session. After stimulation, they recorded 38, 33, and 27 % of the original MVC, which lead them to assume a stronger degree of fatigue and a resulting loss of strength caused by an increased stimulation frequency. They concluded that stimulation at frequencies exceeding 60 Hz in an athletic context does not elicit further increases, therefore lower frequencies should be selected (Dreibati et al., 2010). However, their analysis only refers to the local application of EMS at the m. quadriceps femoris, a WB-EMS session was not performed. Filipovic et al. (2016) define a frequency of ≥ 50 Hz as a precondition for the development of high intensities, the average stimulation frequency for performance increases seem to be 68.6 ± 31.7 Hz (Filipovic et al., 2011).

Concerning our study, no difference was identified among the stimulation frequencies used. However, this could be based on the fact that the stimulation frequency of 20 Hz did not result in optimal, sufficient strength production, and 85 Hz led to faster fatigue. The increased frequency of 85 Hz may not have led to significant increases in performance when compared to 20 Hz. Therefore, future studies may be well advised to select a stimulation frequency around 60 Hz in order to ensure optimal strength production in association with minimum fatigue and performance losses due to higher metabolic demand. The question whether the frequency selected will then have a significant impact on the performance parameters tested cannot be answered clearly at this point. Based on the test participants' feedback, though, a subjectively higher tolerability of the 85 Hz stimulation was observed. A stimulation frequency of 20 Hz felt uncomfortable to some participants due to the perceived individual impulses in the contracting musculature. Unfortunately, we only recorded the RPE values of the intensity and did not make an objective determination of the intensity. Future studies should take into account the degree of fatigue in the athlete or user in training, particularly in terms of periodization in high-performance sports and try to investigate a method to control the current intensity objectively for a better comparison. Training protocols should be selected depending on the state of fatigue. The interrelationship between frequency applied and intensity of the resulting fatigue, as well as the utilization of different stimulation patterns (constant frequency train or doublet frequency train) should be taken into account for an optimal performance increase for a competition and an optimal regeneration after a WB-EMS training (Dreibati et al., 2010). A variation of the stimulation frequency during a training session from higher to lower frequencies may also be suitable for controlling fatigue during the training session and to prevent performance decreases and prolonged regeneration times.

Limitations

Due to the complexity and comprehensive scope of the training and the individual support, no major sample was included in the study. Furthermore, the training program was unspecific and performed without additional electrodes. This was a conscious decision because of the intended utilization of the applications specified by the manufacturers in order to enable comparability with the training programs of WB-EMS studios or commercial use. Additional stimulation of the calf musculature or other muscle groups, as well as an integration of sports-specific exercises (e.g., jumps) or coordinative contents might have increased the jump or sprint performance more significantly. The intensity of the stimulation was determined by an RPE scale, which is quite common in WB-EMS, but does not allow an objective assessment of the intensity. Aspects such as the current level of hydration, skin conductivity or daily form may influence the perception of the applied stimulus. This could be reflected in the objective measurability of the intensity, although subjectively the identical value on the RPE scale is perceived. The use of objective intensity measurement should therefore be investigated in future studies. Previous analyses included the one-repetition maximum or maximal voluntary contraction of various muscle groups, such as m. quadriceps femoris or m. triceps surae, which enabled a more comprehensive conclusion pertaining to the causes of the positive changes of the jump height. Since we were not able to include this type of measurement in this study, an evidence-based interpretation of the interrelation between jump height and strength cannot be provided here. Future studies are recommended to integrate a follow-up test in their study protocol in order to examine delayed adaptations of the muscles and their components due to a prolonged regeneration phase (Maffiuletti et al., 2002; Micke et al., 2018).

Conclusion

Overall, the current findings suggest that 10-week WB-EMS training results in significant improvement of jump (CMJ, SJ) and strength parameters (trunk flexion and extension). A difference in the stimulation frequencies applied was not identified. Both stimulation frequencies were similarly suitable for performance increases. It is, however, currently impossible to make a statement on the effects of frequency selection on long-term aspects, such as regeneration, an offset performance increase after training intensity reduction, or training termination, or whether the stimulation frequency has any significant influence on these factors at all.

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Key points

- A 10-week WB-EMS training improves strength and jump performance parameters of untrained persons significantly.
- There is no difference in performance gains regarding the frequency applied during WB-EMS
- 20 Hz as well as 85 Hz seem appropriate for an effective WB-EMS training

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