©Journal of Sports Science and Medicine (2023) **22**, 226-234
http://www.jssm.org DOI: https://doi.org/10.52082/jssm.2023.226

Research article

Effects of Four Weeks of Static vs. Dynamic Bodyweight Exercises with Whole-Body Electromyostimulation on Jump and Strength Performance: A Two-Armed, Randomized, Controlled Trial

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Abstract

The combination of strength training with complementary whole-body electromyostimulation (WB-EMS) and plyometric exercises has been shown to increase strength and jumping performance in athletes. In elite sport, however, the mesocycles of training are often organized according to block periodization. Furthermore, WB-EMS is often applied onto static strength exercises, which may hamper the transfer into more sport-specific tasks. Thus, this study aimed at investigating whether four weeks of strength training with complementary dynamic vs. static WB-EMS followed by a four-week block of plyometric training increases maximal strength and jumping performance. A total of n = 26 (13 female/13 male) trained adults (20.8 ± 2.2 years, 69.5 ± 9.5kg, 9.7 ± 6.1h of training/w) were randomly assigned to a static (STA) or volume-, load- and work-to-rest-ratio-matched dynamic training group (DYN). Before (PRE), after four weeks (three times weekly) of WB-EMS training (MID) and a subsequent four-week block (twice weekly) of plyometric training (POST), maximal voluntary contraction (MVC) at leg extension (LE), leg curl (LC) and leg press machines (LP) and jumping performance (SJ, Squat Jump; CMJ, counter-movement-jump; DJ, drop-jump) were assessed. Furthermore, perceived effort (RPE) was rated for each set and subsequently averaged for each session. MVC at LP notably increased between PRE and POST in both STA (2335 ± 539 vs. 2653 ± 659N, standardized mean difference [SMD] = 0.528) and DYN (2483 ± 714N vs. 2885 ± 843N, SMD = 0.515). Reactive strength index of DJ showed significant differences between STA and DYN at MID (162.2 ± 26.4 vs. 123.1 ± 26.5 $cm \cdot s^{-1}$, $p = 0.002$, SMD = 1.478) and POST (166.1 ± 28.0 vs. 136.2 ± 31.7 $cm \cdot s^{-1}$, $p = 0.02$, SMD = 0.997). Furthermore, there was a significant effect for RPE, with STA rating perceived effort higher than DYN (6.76 ± 0.32 vs. 6.33 ± 0.47 a.u., $p = 0.013$, SMD = 1.058). When employing a training block of high-density WB-EMS both static and dynamic exercises lead to similar adaptations.

Key words: Periodization, WB-EMS, plyometrics, jump, MVC, fatigue.

Introduction

Electromyostimulation (EMS) has been described as an effective complementary training method suited to potentially improve athletic performance indices of strength, jump and sprint performance (Filipovic et al., 2012). Due to a non-selective recruitment pattern, the activation of fast-twitch muscle fibers occurs at a relatively low force level via EMS (Gregory and Bickel, 2005). Additionally, an increased firing rate and a synchronous recruitment of muscle fibers imposed by EMS training may also lead to improvements in terms of muscular strength and power (Gregory and Bickel, 2005). Using a vest- and belt-electrode-system, multiple muscle groups can be stimulated simultaneously, allowing for multi-joint movements with superimposed whole-body EMS (WB-EMS) (Filipovic et al., 2012).

In trained subjects, both the application of EMS during isometric and dynamic (i.e., alternating between concentric and eccentric) muscle contractions has been shown to impose significant increases in isometric maximal voluntary contraction (MVC) (Filipovic et al., 2012). However, since EMS cannot improve the coordinative aspect of a sport-specific movement, superimposed EMS with voluntary sport-specific movements has been recommended to improve athletic performance (Paillard, 2008). Therefore, the functional transfer of potential increases in MVC into more sport-specific tasks (e.g., explosive power of the lower extremities during jumping exercises) may be more pronounced when performing dynamic movements with superimposed EMS compared to superimposed EMS onto isometric contractions.

While commercial facilities for WB-EMS often recommend a stimulation protocol of 20 minutes per session and a training frequency of one session per week for the general population (Weissenfels et al., 2019; Micke et al., 2021), training regimens with a higher frequency (≥3 sessions per week) have been employed for athletes (Filipovic et al., 2012). The combination of EMS training and plyometric exercises both conducted two to three times a week over the duration of four to eight weeks has been found to increase maximal strength in lower extremities, sprinting and jumping performance (Maffiuletti et al., 2002; Herrero et al., 2006, 2010a). In elite sport, however, the mesocycles of training are often organized according to a block periodization in contrast to simultaneously focusing on many different skills (Issurin, 2010). In these blocks, the training content is focused with a high volume on a few individual abilities (Issurin, 2010). Based on this periodization method, at least in endurance sports, a sequence of training blocks was postulated, in which non-specific basic abilities are trained initially (“Accumulation”), which are further specified in the following block (“Transformation”), until

Received: 26 October 2022 / Accepted: 31 March 2023 / Published (online): 01 June 2023

finally a sport-specific transfer of the trained skills takes place in a third phase (“Realization”) (Issurin, 2010).

Against this background, this randomized controlled trial aimed at elucidating whether a four-week block of either static or dynamic WB-EMS followed by a four-week block of realization consisting of plyometric exercises is suitable to increase maximal strength and jumping performance in young and physically active adults. We hypothesized that the functional transfer into a sport-specific context may be more pronounced when performing dynamic movements with superimposed EMS compared to superimposed EMS onto isometric contractions. These results might impact the usage of WB-EMS as a complementary training tool to intensify strength training in trained subjects.

Methods

Participants

Based on a previously conducted randomized control trial (Micke et al., 2018), an a priori conducted power analysis (α =0.05, study power (1-β-error) = 0.95, r = 0.5, effect size η_p^2 = 0.137 (f = 0.399)) performed using g*Power (Version 3.1.9.6) required a sample size of n = 24. Assuming low to moderate rates of dropout, a total of n = 31 sport students were recruited. Inclusion criteria were (I) aged ≥ 18 years, (II) at least two years of experience in strength training and (III) no acute or chronic medical condition that potentially impede the completion of all experimental and training sessions. After the first laboratory visit for physical performance testing, all included participants were either assigned to a static training group (STA) or a dynamic training group (DYN) using the minimization method (Scott et al., 2002). Age, sex, mean training activity per week (in h) and years of strength training experience were used as strata for the minimization procedure. Due to personal reasons and injuries not related to the study, two participants of the STA group and one participant of the DYN group had to discontinue the study before its completion. Further, due to technical reasons, laboratory testing for two participants could not be carried out. Therefore, a total of n = 26 participants who were attended at least 75% of all training sessions could be included in the final analyses (Table 1). The study was approved by the local ethical committee (144/2018) and all participants signed an informed written consent prior to start of the study.

Study design

The study was designed as a randomized two-group, parallel trial. The intervention consisted of two phases: (I) Four weeks of bodyweight strength training with complementary WB-EMS, conducted three times a week under static (STA) or dynamic conditions (DYN) followed by (II) four weeks of realisation phase without superimposed WB-EMS, with training conducted twice weekly. Prior to the intervention (PRE), between phase I and II (MID), and after phase II (POST) participants visited the laboratory for physical performance testing.

Testing procedures

MVC (in N) under isometric conditions was assessed at leg extension (LE), leg curl (LC) and leg press (LP) machines (Edition-Line, gym80, Gelsenkirchen, Germany) at PRE, MID and POST. Each machine was equipped with a strain gauge sensor (KM1506, megaTron, Munich, Germany) fitted in line with the steel belt lifting the machines weight plates. Via a PC-2-Channel-Interface and the corresponding software strength data were recorded at a rate of 100Hz (IsoTest 2, mechaTronic, Hamm, Germany). This equipment has been considered as reliable for isometric testing (CV <8%, ICC = 0.95 - 0.97) (Dörmann, 2011). For assessing MVC, participants performed three maximal isometric test attempts at LE, LC, and LP, each. In accordance with Maffiuletti and colleagues (2016), participants were instructed to reach the peak force as quickly as possible by squeezing “hard and fast”. Isometric tests at both LE and LP were conducted in an upright sitting position at an inner knee angle of 120° (hip angle 90°). Isometric strength tests at LC were conducted in a prone position with an inner knee angle of 150° (hip angle 150°). For each of the three attempts of MVC testing, the highest consecutive force values averaged over 150ms were calculated. Subsequently the two best attempts were averaged and used for all further analyses.

Table 1. Demographic variables (mean values ± standard deviation) for anthropometric and performance data at baseline for the static (STA) and dynamic (DYN) training group. Furthermore, standardized mean difference (SMD), as well as the *p*-value, and partial eta squared (η_p^2) of rANOVA are indicated.

Parameter	STA (n = 13)	DYN (n = 13)	SMD	*p*-value	η_p^2
Sex (F/M)	6/7	7/6	-	-	-
Age [Yrs]	21.1 ± 2.4	20.5 ± 1.9	0.245	0.538	0.016
Mass [Kg]	71.4 ± 8.8	67.6 ± 10.1	0.407	0.309	0.043
Height [m]	1.79 ± 0.09	1.74 ± 0.11	0.507	0.208	0.065
Training Age [Yrs]	4.6 ± 2.5	4.9 ± 2.2	0.115	0.772	0.004
Training·Week^{-1} [h]	9.7 ± 6.5	9.7 ± 6.0	0.006	0.988	0.000
MVC LE [N]	1937 ± 528	1994 ± 502	0.109	0.783	0.003
MVC LC [N]	1168 ± 292	1005 ± 313	0.537	0.184	0.072
MVC LP [N]	2391 ± 525	2483 ± 714	0.148	0.709	0.006
SJ [cm]	32.8 ± 6.4	33.0 ± 7.0	0.033	0.933	0.000
CMJ [cm]	34.0 ± 6.2	33.0 ± 7.9	0.147	0.712	0.006
DJ height [cm]	27.1 ± 4.8	26.8 ± 6.0	0.050	0.901	0.001
DJ contact time [s]	0.184 ± 0.048	0.178 ± 0.025	0.149	0.706	0.006
DJ RSI [cm·s^{-1}]	141.3 ± 41.7	144.1 ± 38.0	0.072	0.856	0.001

MVC = maximal voluntary contraction; LE = leg extension machine; LC = leg curl machine; LP = leg press machine; SJ = squat jump; CMJ = counter-movement-jump; DJ = drop jump; RSI = reactive strength index.

Vertical jumping was evaluated employing the Squat Jump (SJ), Counter-Movement-Jump (CMJ) and Drop Jump (DJ, 0.40 m drop height) on a force plate at 1000 Hz (FP4060-15 - TM-4000, Bertec Corporation, Columbus, USA). During all jumping tests, the arms had to be placed on the hips (akimbo). Three trials of SJ, CMJ and DJ with approximately 30s of rest between attempts were conducted at PRE, MID and POST. Jump height was determined via integration of the ground reaction forces (Linthorne, 2001). Furthermore, for DJ, the reactive strength index (RSI; jumping height in cm divided by contact time in s) was calculated (Struzik et al., 2016). High reliability for this testing procedure has been reported previously (ICC = 0.92 - 0.98, CV = 1.3 - 4.1%) (Hori et al., 2009). The respective two best trials of SJ, CMJ and DJ were used for all further analyses.

The acute recovery and stress status (ARSS) was assessed at PRE, MID and POST using the validated German version of the ARSS questionnaire (Nässi et al., 2017). The test comprises 32 adjectives describing physical, emotional, mental, and overall aspects of recovery and stress to be rated on a seven-point Likert scale ranging from 0 (does not apply at all) to 6 (fully applies) (Hitzschke et al., 2016). The acute recovery and stress status is measured in 8 different dimensions: physical performance capacity (PPC), mental performance capacity (MPC), emotional balance (EB), overall recovery (OR), muscular stress (MS), lack of activation (LA), emotional imbalance (EI), and overall stress (OS).

Training procedure

For WB-EMS a commercially available EMS device was used (MIHA BODYTEC II, miha bodytec GmbH, Gersthofen, Germany). Via electrical cords, a stimulation vest for the torso and belt surface electrodes for the upper and lower extremities were connected to the controlling unit. Two bilaterally paired electrodes integrated in the vest were used to stimulate the lower back (length × height: 14cm × 11cm), trapezius muscle (23cm × 10cm), latissimus dorsi (14cm × 9cm), abdominal muscles (23cm × 11cm) and chest muscles (15cm × 4.5cm). Furthermore, two surface electrodes were wrapped around the buttocks, thighs, and upper arms of the participants, respectively. Depending on the body dimensions, different sizes of belt electrodes (small/medium/large) were used to provide stimulation of the glutei (13cm × 10cm), the quadriceps/hamstring muscles (35.5 - 60.5cm × 4cm) and the biceps/triceps brachii (20.5 - 32.5cm × 4cm) (for a detailed description and picture of the device and electrodes, see (Dörmann et al., 2019)). During an initial familiarization phase, participants were instructed to reach an electrical stimulation intensity, at which the perceived pain could just be tolerated (individual maximal tolerable pain threshold; IPT). For this purpose, the main controller of the EMS device was turned up to its maximal intensity (100%). Afterwards, starting at the thighs and the buttocks and continuing with the lower back, abdominal, chest, latissimus and finally the arms, the IPT was determined for each of the bilaterally paired electrodes separately by using the individual controller of the EMS device. For the training sessions, an intensity of 70% IPT was set by turning down the main controller to an intensity of 70%. Impulse frequency was set at 85Hz with an impulse duration of 350μs and a bipolar and rectangle impulse type. The stimulation-to-rest-ratio was set at 6:4 seconds. Due to individual differences in the resistance of tissue structures, it cannot be precisely determined, which intensity ultimately reached the muscles (Lake, 1992). During the intervention, perceived exertion (RPE) was rated on the 1-10 RPE scale after each set (Borg et al., 1985). For each set, a target intensity of 6-8 on the RPE scale was aimed for. For further analyses, the mean value of all RPE ratings for each set and each session for all four weeks of EMS training was calculated for all participants. EMS intensity was decreased or increased for the subsequent set, when the RPE rating was above or below the target intensity. The mean value of EMS intensity of the electrodes of the legs, the glutei, and the upper body (lower back, trapezius muscles, latissimus dorsi, abdominal muscles, chest muscles and upper arms) for each set and each session for all four weeks of WB-EMS training was calculated for all participants.

During the first four weeks of the intervention, both groups completed three supervised training sessions per week. Based on previous research with WB-EMS (Micke et al., 2018; Dörmann et al., 2019), these training sessions consisted of a strength training program comprising two exercises (Bulgarian split squat and Glut-Ham-Bridge/Sliding Leg Curl) conducted with the participants' own bodyweight as resistance and superimposed WB-EMS. Both exercises were performed in 3 sets of 10 continuous repetitions and 120 seconds of rest between the sets (3 × 10 repetitions for each leg for Bulgarian split squat). For each repetition of both exercises, the STA group took a predefined position (120° inner knee angle for Bulgarian Split Squat and 130° inner knee angle for Glut-Ham-Bridge) and maintained this position over the six seconds of electrical stimulation of the stimulation cycle. The DYN group performed a dynamic movement (three seconds concentric and three seconds eccentric) over the predefined range of motion (180-90° of inner knee angle for Bulgarian Split Squat and 180-100° for Sliding Leg Curl) during the six seconds of stimulation of the stimulation cycle. Accordingly, both training groups were matched in terms of exercise selection, total training volume and work-to-rest-ratio (Table 2).

During the realization phase (week 5 to 8), both groups completed two supervised training sessions per week. Both groups completed the same three exercises

Table 2. Four-week WB-EMS training protocol for static (STA) and dynamic training group (DYN).

Exercise	Group	Load (set × reps)	Inter-Set-Rest [s]	Knee angle/ ROM [°]	con-iso-ecc-iso [s]	Duty Cycle [%]
Bulgarian Split	STA	3 × 10	120	120	0 – 6 – 0 – 4	60
Squat	DYN	3 × 10	120	180-90	3 – 0 – 3– 4	60
Glut-Ham-Bridge	STA	3 × 10	120	130	0 – 6 – 0– 4	60
Sliding Leg Curl	DYN	3 × 10	120	180-100	3 – 0 – 3– 4	60

ROM = range of motion; con = concentric; iso = isometric; ecc = eccentric.

(3 × 10 repetitions of lateral jumps over 120 cm, 3 × 5 repetitions of 3 hurdle jumps, and 3 × 15 seconds of Skipping with resistance) without superimposed WB-EMS. All participants were encouraged to perform every repetition with maximal intensity.

Statistical analysis

Data are presented as mean ± SD. All data were initially assessed for normal distribution and variance homogeneity (Razali and Wah, 2011). To examine baseline group differences (STA vs. DYN) for anthropometric data and the respective outcome measures (LE, LC, LP, SJ, CMJ and DJ) univariate (one factor) repeated measures of variance (rANOVA) were conducted. Furthermore, separately conducted 2 (group: STA vs. DYN) × 3 (time: PRE vs. MID vs. POST) rANOVA were calculated for each outcome measure. Mauchly's test for sphericity was performed and, if necessary, Greenhouse-Geisser (GG) corrections were applied. Effect sizes for rANOVA are provided as partial eta squared (η_p^2) with ≥0.01, ≥0.06, ≥0.14 indicating small, moderate, and large effects, respectively (Cohen, 1988). In case of significant interaction effects, Bonferroni post-hoc tests were subsequently computed. Furthermore, to assess group differences in EMS intensity and mean RPE, independent t-tests were calculated. For pairwise effect size comparison, standardized mean differences (SMD) were calculated as differences between means divided by the pooled standard deviations (trivial: | SMD | < 0.2, small: 0.2 ≤ | SMD | < 0.5, moderate: 0.5 ≤ | SMD | < 0.8, large: | SMD | ≥ 0.8) (Cohen, 1988). Statistical analyses were performed using R (version 3.6.2) in its integrated development environment RStudio (version 1.4.1106). For all calculations, a *p*-value below 0.05 was considered significant.

Results

Maximal voluntary contraction

For LE, LC and LP no significant mode × time interaction effects were found ($p \geq 0.075$, $\eta_p^2 \leq 0.111$). However, a simple main effect analysis of time revealed statistically significant and large time effects for both LC (F(2, 44) = 4.69, $p = 0.014$, $\eta_p^2 = 0.176$) and LP (F(1.57, 34.56) = 23.56, *p[GG]* < 0.001, $\eta_p^2 = 0.517$).

Pairwise comparison of MVC at LC revealed slightly lower values at MID compared to PRE and POST for DYN (SMD = 0.343 & 0.312, respectively). Pairwise comparison of MVC at LP showed larger values at POST compared to PRE and MID for both STA (SMD = 0.528 & 0.486, respectively) and DYN (SMD = 0.515 & 0.339, respectively) (Table 3).

Vertical jumping performance

For SJ and CMJ no significant mode × time interaction effects were found ($p \geq 0.123$, $\eta_p^2 \leq 0.087$). Simple main effect analyses for time, however, showed statistically significant effects in both SJ (F(2, 46) = 5.96, $p = 0.005$, $\eta_p^2 = 0.206$) and CMJ (F(2, 46) = 5.75, $p = 0.006$, $\eta_p^2 = 0.200$). Pairwise comparison of SJ height indicated lower values at MID compared to PRE and POST for DYN (SMD = 0.580 & 0.405). Furthermore, pairwise comparison of CMJ jumping height indicated slightly lower values at MID compared to PRE and POST for DYN (SMD = 0.445 & 0.346) (Table 3).

Although no main or interaction effects were found For DJ height (Figure 1A) and DJ ground contact time (Figure 1B), a statistically significant and large mode × time interaction effect was found for DJ RSI (F(2, 44) = 7.66, $p = 0.001$, $\eta_p^2 = 0.258$). Subsequently performed post-hoc testing revealed statistically significant differences between STA and DYN at both MID (162.2 ± 26.4 vs. 123.1 ± 26.5 $cm \cdot s^{-1}$, $p = 0.002$, SMD = 1.478) and POST (166.1 ± 28.0 vs. 136.2 ± 31.7 $cm \cdot s^{-1}$, $p = 0.02$, SMD = 0.997) (Figure 1C).

Acute recovery and stress status

Overall recovery showed a significant main effect for time (F(2, 42) = 10.43, $p < 0.001$, $\eta_p^2 = 0.510$). Pairwise comparison of time points revealed higher values at PRE and POST compared to MID for DYN (SMD = 1.033 & 1.111, respectively; Table 4). Furthermore, in terms of stress, all four stress-related dimensions showed significant main effects for time ($p \leq 0.001$, $\eta_p^2 \geq 0.276$). For muscular stress, pairwise comparison indicated higher values in DYN at MID compared to PRE and POST (SMD = 1.509 & 1.500, respectively). Furthermore, overall stress was rated higher at MID than at PRE and POST in both DYN (SMD = 1.248 and 1.180, respectively) and STA (SMD = 1.243 and 1.148, respectively; Table 4).

Table 3. Maximal voluntary contraction (MVC) for the static (STA) and dynamic training group (DYN) at leg extension machine (LE), leg curl machine (LC), and leg press machine (LP) as well as squat jump (SJ) and counter-movement-jump performance (CMJ) during PRE, MID, and POST testing. Also, the *p*-value and partial eta squared (η_p^2) of rANOVA are indicated.

Parameter	Group	PRE	MID	POST	rANOVA *p*-value (η_p^2)		
					time	group	time×group
MVC LE [N]	STA	1836 ± 400	1862 ± 415	1982 ± 415	0.158 (0.077)	0.626 (0.011)	0.360 (0.044)
	DYN	1994 ± 502	1935 ± 444	1997 ± 433			
MVC LC [N]	STA	1106 ± 254	1093 ± 202	1103 ± 209	0.014 (0.176)	0.208 (0.071)	0.075 (0.111)
	DYN	1005 ± 313	911 ± 229	991 ± 281			
MVC LP [N]	STA	2335 ± 539	2357 ± 555	2653 ± 659	< 0.001 (0.517)	0.449 (0.026)	0.542 (0.024)
	DYN	2483 ± 714	2615 ± 745	2885 ± 843			
SJ [cm]	STA	31.7 ± 5.3	30.7 ± 4.4	31.2 ± 3.8	0.005 (0.206)	0.924 (0.000)	0.123 (0.087)
	DYN	33.0 ± 7.0	29.3 ± 5.7	32.0 ± 7.5			
CMJ [cm]	STA	33.1 ± 5.4	31.9 ± 4.7	32.6 ± 4.8	0.006 (0.200)	0.715 (0.006)	0.276 (0.054)
	DYN	33.0 ± 7.9	29.9 ± 5.9	32.1 ± 6.8			

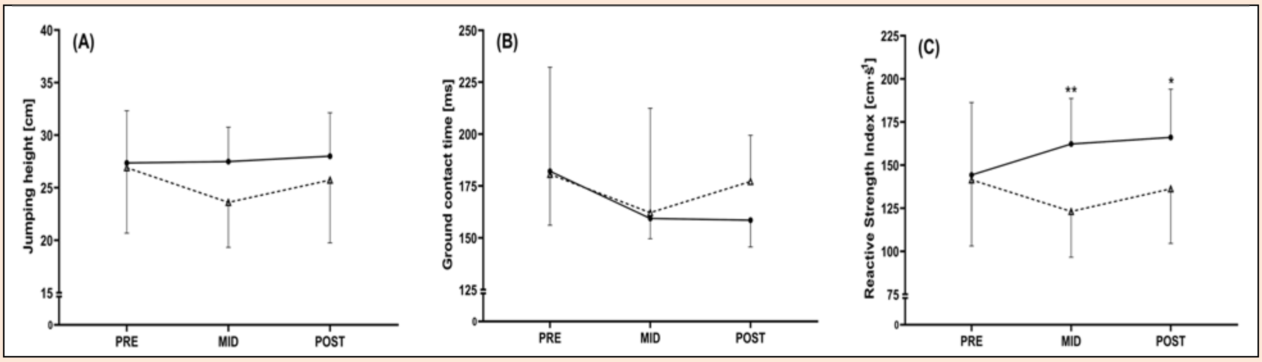

Figure 1. Drop-Jump jumping height (A), ground contact time (B) and reactive strength index (C) for the static (solid lines + circles) and dynamic training group (dashed lines + triangles) during PRE, MID, and POST testing. *significantly different from dynamic training group (p < 0.05); ** significantly different from dynamic training group (p < 0.01).

Table 4. Acute recovery and stress status (ARSS) rated on the 8 different scales for static (STA) and dynamic training group (DYN) during PRE, MID, and POST testing. Furthermore, the p-value and partial eta squared (η_p^2) of rANOVA are indicated.

ARSS Scale	Group	PRE	MID	POST	2×3 rANOVA *p*-value (η_p^2) time	group	time×group
Recovery							
PPC	STA	4.68 ± 0.55	4.39 ± 0.83	4.70 ± 0.74	$p = 0.011$ (0.221)	$p = 0.120$ (0.111)	$p = 0.267$ (0.061)
	DYN	4.42 ± 0.89	3.52 ± 1.14	4.33 ± 1.14			
MPC	STA	5.09 ± 0.59	4.59 ± 0.90	4.70 ± 0.88	$p < 0.001$ (0.322)	$p = 0.699$ (0.007)	$p = 0.881$ (0.006)
	DYN	4.98 ± 0.90	4.38 ± 1.04	4.60 ± 1.18			
EB	STA	5.14 ± 0.70	4.52 ± 0.90	4.83 ± 0.77	$p = 0.017$ (0.204)	$p = 0.994$ (0.000)	$p = 0.729$ (0.011)
	DYN	5.06 ± 0.67	4.65 ± 1.08	4.79 ± 1.03			
OR	STA	4.54 ± 0.69	4.02 ± 0.86	4.57 ± 0.91	$p < 0.001$ (0.332)	$p = 0.445$ (0.028)	$p = 0.311$ (0.054)
	DYN	4.48 ± 1.07*	3.42 ± 0.98	4.52 ± 1.00*			
Stress							
MS	STA	0.91 ± 0.83	1.77 ± 1.10	0.91 ± 0.83	$p < 0.001$ (0.451)	$p = 0.481$ (0.024)	$p = 0.082$ (0.112)
	DYN	0.77 ± 1.02**	2.75 ± 1.55	0.77 ± 1.04**			
LA	STA	0.27 ± 0.43	0.86 ± 0.65	0.52 ± 0.68	$p = 0.001$ (0.276)	$p = 0.425$ (0.031)	$p = 0.780$ (0.012)
	DYN	0.38 ± 0.72	1.19 ± 1.27	0.83 ± 1.12			
EI	STA	0.57 ± 0.82	1.11 ± 0.61	0.43 ± 0.48	$p < 0.001$ (0.292)	$p = 0.933$ (0.000)	$p = 0.236$ (0.066)
	DYN	0.23 ± 0.39	1.10 ± 1.12	0.71 ± 1.20			
OS	STA	0.61 ± 0.61*	1.48 ± 0.78	0.64 ± 0.68*	$p < 0.001$ (0.478)	$p = 0.099$ (0.124)	$p = 0.325$ (0.052)
	DYN	0.93 ± 0.89**	2.35 ± 1.34	0.98 ± 0.95*			

PPC = physical performance capacity; MPC = mental performance capacity; EB = emotional balance; OR = overall recovery; MS = muscular stress; LA = lack of activation; EI = emotional imbalance; OS = overall stress; * significantly different from MID ($p < 0.05$); ** significantly different from MID ($p < 0.01$).

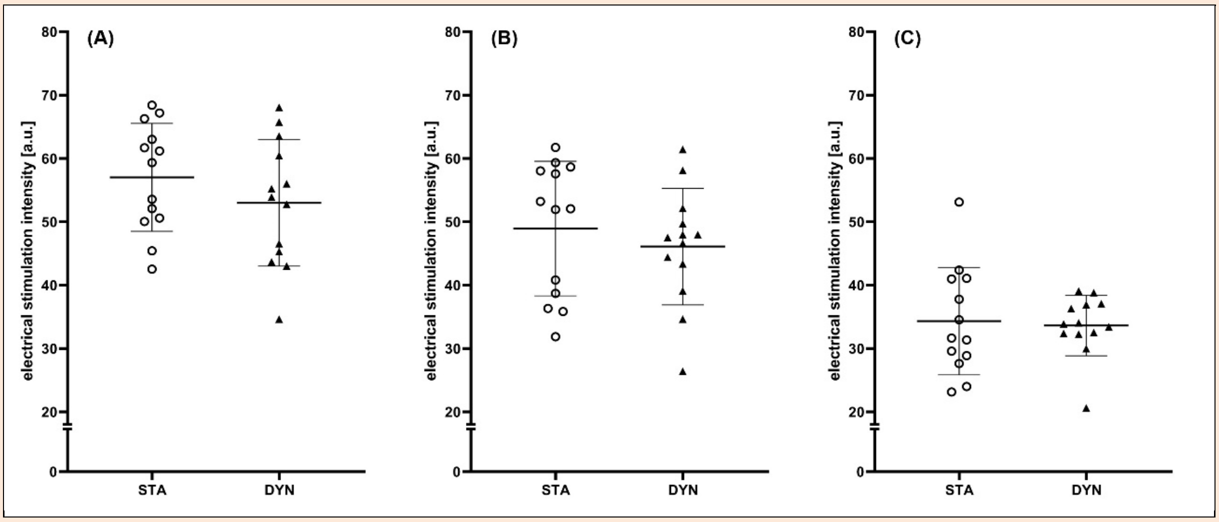

Figure 2. Mean stimulation intensity of the thighs (A), glutei (B) and the upper body (C) during each WB-EMS session for all participants of the static (STA, circles) and dynamic training group (DYN, triangles). Furthermore, group mean values and standard deviations are indicated additionally.

EMS stimulation intensity

No statistically significant differences were found between STA and DYN in terms of electrical stimulation intensity of the legs (57.0 ± 8.5 vs. 53.0 ± 10.0 a.u., $t(24) = 1.11$, $p = 0.278$, SMD = 0.435; Figure 2A), the glutei (48.9 ± 10.6 vs. 46.1 ± 9.2 a.u., $t(14) = 0.73$, $p = 0.475$, SMD = 0.285; Figure 2B) and the upper body (34.3 ± 8.5 vs. 33.6 ± 4.8 a.u., $t(18.9) = 0.25$, $p = 0.804$, SMD = 0.099; Figure 2C).

Rating of perceived exertion

During the four weeks of WB-EMS training, the mean rating of RPE was statistically significant higher for STA compared to DYN (6.76 ± 0.32 vs. 6.33 ± 0.47 a.u., $t(24) = 2.70$, $p = 0.013$, SMD = 1.058) (Figure 3).

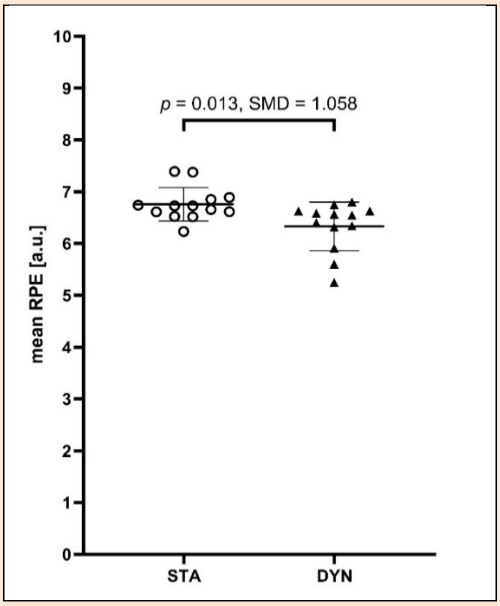

Figure 3. Mean perceived effort of each WB-EMS session for all participants of the static (STA, circles) and dynamic training group (DYN, triangles). Furthermore, mean values and standard deviations, p-values of the independent t-test and standardized mean differences (SMD) are indicated additionally.

Discussion

This randomized controlled trial investigated whether a four-week block of either static or dynamic WB-EMS followed by a four-week block of realization consisting of plyometric exercises is suitable to increase maximal strength and jumping performance in young and physically active adults. No improvements in maximal isometric voluntary contraction at leg extension and leg curl machine as well as in counter-movement-jump and squat-jump were found for neither the static nor the dynamic training group after both the WB-EMS and realization training block. However, maximal isometric voluntary contraction at leg press machine notably increased between PRE and POST in both training groups. Furthermore, the static training group showed statistically significant higher values for drop jump reactive strength index compared to the dynamic training group after both training blocks. Interestingly, electrical stimulation intensity and rating of acute recovery and stress status did not differ between both groups, while the static training group reported higher ratings of perceived effort.

Similar to our findings, previous research revealed improved strength adaptations in the lower extremities via local EMS (Maffiuletti et al., 2000, 2002, 2009; Herrero et al., 2006, 2010a; 2010b). In a randomized controlled trial (Herrero et al., 2010b), physical education students were assigned to either a passive control group, a weight training group, or a weight training group with superimposed EMS of the quadriceps muscle (rectangular impulse form, impulse frequency 120Hz, impulse width 400µs). After four weeks of training (4x/week, 8×10 repetitions, 70% 1RM at knee extension machine) the EMS training group showed significantly higher improvements in maximal voluntary contraction under isometric conditions at the knee extension machine than the weight-only training group (+40.2% vs. +31.4%). These differences were even higher after two weeks of subsequent detraining (+49.1% vs. +24.5%) (Herrero et al., 2010b). A delayed increase in performance after two weeks of detraining following a training block with EMS has also been described by other authors (Herrero et al., 2010a; Wirtz et al., 2016; Micke et al., 2018). Micke and colleagues (2018) speculated, that these delayed adaptation processes may be explained by an accentuated activation of fast motor units at comparably low force levels (Gregory and Bickel, 2005) and the continuous stimulation and subsequently fatiguing effects caused by contractile activity of the same motor units throughout the intervention (Requena Sánchez et al., 2005).

In the present study, no increase in maximum voluntary contraction of the lower extremities was found in either group, neither after the first block of four weeks of WB-EMS training, nor after the second four-week block of realization consisting of plyometric exercises. This is of particular interest, as the four weeks of realization training may be considered as a sufficient detraining phase (Filipovic et al., 2011). Although the participants performed all exercises with their own bodyweight as resistance, the mean RPE values of the static (6.76 ± 0.32 a.u.) and dynamic training group (6.33 ± 0.47 a.u.) correspond to a training intensity of 70-80% of maximal voluntary contraction (Pincivero et al., 2003) and are therefore comparable to the training intensity used by Herrero and colleagues (Herrero et al., 2010b) (70% maximal voluntary contraction). However, in the present study, 3x10 repetitions were performed three times weekly for the hamstring muscles (Sliding leg curls or Glut-Ham-bridge) and 3x10 repetitions per leg for the leg extensors (Bulgarian Split Squats). Thus, resulting in 90 repetitions per week for hamstrings and 90 repetitions per week and leg for leg extensor muscles. In the study of Herrero and colleagues (2010b), 8x10 repetitions were performed 4 times per week on the leg extension machine (320 repetitions per week). Similarly, higher training volumes were employed in studies by Maffiuletti and colleagues (2000) (3x/w, 48 isometric contractions of knee extensor muscles at 80% maximal voluntary contraction: 144 repetitions per week) and Herrero and colleagues (2006) (4x/w, 53 isometric contractions of knee extensor muscles at the individual pain threshold + plyometric training twice weekly: 212 repetitions per week) inducing significant improvements in maximal strength. Since a graded dose-response relationship between weekly sets performed and strength gain exists and especially in well-trained individuals a higher training volume is necessary to induce further gains in maximal strength (Ralston et al., 2017), the total training volume per muscle group in our study may be considered too low (~28.1 - 62.5% of the volume employed by aforementioned studies). However, in a study (Herrero et al., 2010a) that replicated the strength training of the aforementioned study by Herrero and colleagues (Herrero et al., 2010b) but added plyometric training (twice weekly; 90-105 horizontal/drop jumps per session), lower strength adaptations were reported for both the strength training group with superimposed EMS and the strength training group after 4 weeks of intervention and two weeks of detraining. It was therefore concluded that at a lower training volume, strength training with superimposed EMS is more effective in enhancing muscular strength than strength training without superimposed EMS (Herrero et al., 2010a). In this context, despite the lower number of repetitions per week and muscle group in our study, when comparing the total time of stimulation, the time under electromyostimulation was longer in our study compared to the studies conducted by Herrero and colleagues (2010b) and Maffiuletti and colleagues (2000) (1,080s/w vs. 960s/w & 432s/w, respectively). Additionally, all of the aforementioned studies (Maffiuletti et al., 2000, 2002, 2009; Herrero et al., 2006, 2010a; 2010b) comprised local electrical muscle stimulation of only the leg extensor muscles, whereas in the present study electrical stimulation of the whole body was used.

In a study comprising a similar population, training volume and exercise selection as our study (eight weeks of training with complementary WB-EMS, two sessions per week including strength and plyometric exercises) only moderate increases in maximal isometric voluntary contraction at the leg extension machine (+6.9%), and no increases in maximal isometric voluntary contraction at the leg curl and leg press machines were found (Micke et al., 2018). It is therefore possible, that the simultaneous stimulation of multiple muscle groups induces higher levels of fatigue at a lower training intensity resulting in a reduced adaptation potential for WB-EMS. However, this remains speculative, as measuring fatigue was not the focus of the present study.

Interestingly, the mean perceived exertion during WB-EMS training was reported to be higher in the static training group compared to the dynamic training group. However, an underestimation of perceived exertion during moderate to high-intensity isometric contractions has been reported previously (Hasson et al., 1989; Pincivero et al., 1999). This seems plausible, as in the present study a higher muscular stress level and lower rating of overall recovery level were only reported in the dynamic training group after the four-week block of EMS-training. Furthermore, neuromuscular performance (indicated by the reactive strength index of drop jump) was significantly lower in the dynamic compared to the static training group after the four-week block of EMS-training and the subsequent four-week block of plyometric training. However, at least in the static training group, we found moderate, although not statistically significant, increases in drop jump reactive strength index (SMD = 0.613). Similarly, small, but not statistically significant performance increases in drop jump height (SMD = 0.360) were reported after eight weeks (16 training sessions) of strength and plyometrics training with complementary WB-EMS in young, trained adults (Micke et al., 2018). In this regard, it has been suggested that a higher number of training sessions per week or a longer intervention duration is required to transfer adaptations gained by WB-EMS training into sport specific movements such as jumping (Filipovic et al., 2016).

A limitation of the study is that due to individual differences in the resistance of tissue structures (e.g., subcutaneous fat thickness), it cannot be precisely determined, which electrical stimulation intensity ultimately reached the muscle fibres (Lake, 1992). These effects might be more pronounced, as we included participants of both sexes. However, even though women demonstrate significantly lower supramotor thresholds compared to men, no significant differences are shown at the motor threshold (Maffiuletti et al., 2008). Thus, the individual pain tolerance to the electrical current may be seen as the limiting factor for EMS exercises (Reed, 1997). However, by determining the individual pain threshold and adjusting the stimulation intensity to 70% of this threshold, it was ensured that all participants were stimulated at a similar level. Furthermore, the mean stimulation intensity of the individual muscle groups showed no difference between the two training groups. Therefore, both subjective and objective parameters indicate a similar stimulation intensity for both groups. Additionally, during the skipping exercise, we did not record the total number of ground contacts for each foot. However, as all participants were instructed to perform this exercise at maximal velocity at maximal effort, this allows for a comparison between the two conditions.

Conclusion

In conclusion, neither a four-week block of static nor dynamic bodyweight training with complementary WB-EMS followed by a four-week block of realization consisting of plyometric exercises improves maximal strength and jumping performance in young and physically active adults. Although perceived effort was rated higher in the static training group, neuromuscular performance indices (e.g., drop jump reactive strength index) and rating of the acute recovery and stress status indicated more fatiguing effects in the dynamic training group. Further research should thus focus on possible differences between dynamic and static WB-EMS training regimens in terms of muscle activation and maximal strength assessment under dynamic conditions (e.g., 1-RM squat or loaded jumps). Nevertheless, these findings are in line with the conclusions of a recent network meta-analysis (Micke et al., 2022): To effectively improve strength and sport-specific parameters of athletes, low EMS volume, relatively high stimulation intensity, and movement-specific exercises seem to be important. Therefore, a lower EMS volume and a longer training period appear to be beneficial compared to a short block of high volume and intensity.

Acknowledgements

This study was financially supported by the German Federal Institute of Sports Science (BISp) under Grant AZ 070502/19-20. The funders had no role in study design, data collection and analysis, decision to publish, or preparation of the manuscript. The experiments comply with the current laws of the country in which they were performed. The authors have no conflict of interest to declare. The datasets generated and analyzed during the current study are not publicly available, but are available from the corresponding author who was an organizer of the study.

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Key points

- 4-week block of high-density bodyweight training with complementary WB-EMS only leads to minor improvements in lower extremity maximal strength.
- Jumping performance was not statistically significant improved following a 4-week block of high-density bodyweight training with complementary WB-EMS.
- Perceived exertion was rated statistically significant higher for static compared to dynamic WB-EMS.

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