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Research article

Effects of Loaded Squat Exercise with and without Application of Superimposed EMS on Physical Performance

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Abstract
The aim of the present study was to investigate the effects of a multiple set squat exercise training intervention with superimposed electromyostimulation (EMS) on strength and power, sprint and jump performance. Twenty athletes from different disciplines participated and were divided into two groups: strength training (S) or strength training with superimposed EMS (S+E). Both groups completed the same training program twice a week over a six week period consisting of four sets of the 10 repetition maximum of back squats. Additionally, the S+E group had EMS superimposed to the squat exercise with simultaneous stimulation of leg and trunk muscles. EMS intensity was adjusted to 70% of individual pain threshold to ensure dynamic movement. Strength and power of different muscle groups, sprint, and vertical jump performance were assessed one week before (pre), one week after (post) and three weeks (re) following the training period. Both groups showed improvements in leg press strength and power, countermovement and squat jump performance and pendulum sprint ($p < 0.05$), with no changes for linear sprint. Differences between groups were only evident at the leg curl machine with greater improvements for the S+E group ($p < 0.05$). Common squat exercise training and squat exercise with superimposed EMS improves maximum strength and power, as well as jumping abilities in athletes from different disciplines. The greater improvements in strength performance of leg curl muscles caused by superimposed EMS with improvements in strength of antagonistic hamstrings in the S+E group are suggesting the potential of EMS to unloaded (antagonistic) muscle groups.

Key words: Electrical stimulation, strength training, MVC, peak power output, sprint, change of direction speed, jump height.

Introduction

Resistance training is the predominant method to enhance strength and performance in power related abilities like sprinting and jumping (Comfort et al., 2012). Squat exercise with additional load is one common exercise shown to improve lower limb strength and muscular power, as well as jump and sprint performance (Chelly et al., 2009; Cormie et al., 2010). Furthermore, Electromyostimulation (EMS) is known to be an effective method for improving the aforementioned factors of athletic performance too (Filipovic et al., 2012). The reasons for the improvements and improved adaptations with EMS are the higher number of motor units recruited during exercise with EMS compared to dynamic voluntary contractions only (Kots and Chiwlon, 1971) and, additionally, activation of fast-twitch fibers at relatively low force levels (Gregory and Bickel, 2005).

Furthermore, EMS superimposed to dynamic movements can also increase activation levels at different muscle length and during different contraction modes, e.g. during eccentric work phases (Westing et al., 1990). Willoughby and Simpson (1998) hypothesized that type II muscle fibers remain active during EMS in contrast to the normal continuing de-recruitment of motor units during the eccentric phase. Therefore, intensification of loaded squat exercise by superimposed EMS can potentially induce an increase in recruitment of high-threshold motor units (Dudley, 1992). EMS potentially supports the athlete to achieve power and sport-specific movement velocities within resistance training (Young, 2006) by increased firing rate and a synchronization of motor units (Gregory and Bickel, 2005). Further advantages on muscular strength and power could be achieved by whole body EMS devices that are able to stimulate several muscle groups simultaneously, e.g. muscle chains or agonist/antagonist during multi joint movement like squat exercise. Stimulation of muscle chains could support squats by compensating usual weak points like hip extensor (Lynn and Noffal, 2012) or the lower back muscles (Hamlyn et al., 2007). Furthermore, it is possible that counterproductive firing of agonist and antagonist evoke demands on voluntary contraction, especially on a reduced co-activation of antagonistic muscles, to continue the required dynamic exercise.

To improve muscle strength and power by the use of EMS the settings such as impulse intensity; stimulation frequency; impulse width; pulse type; and stimulation ratio have to be taken into account (Filipovic et al., 2011). In most studies a biphasic impulse type rather than a monophasic is applied (Babault et al., 2007; Maffiuletti et al., 2009). This offers advantages for applying high stimulation intensities and, therefore, has a higher influence on the enhancement of strength abilities. Furthermore, muscle contraction force can be regulated by varying the level of impulse intensity (Lake, 1992). However, due to the resistance of different tissue structures it is not possible to precisely determine the impulse intensity (mA) that ultimately reaches the muscles.

Most studies used the maximum pain threshold (maximum tolerated amperage) to regulate the maximum impulse intensity (Brocherie et al., 2005; Maffiuletti et al., 2009). However, a high level of muscle tension due to

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EMS limits the range of dynamic movements. Therefore, in dynamic exercise modes with superimposed EMS, the impulse intensity has to be adjusted to ensure sufficient movement. There are lacks of studies dealing with dynamic exercise and superimposed EMS. It has been shown that 70% of maximum pain threshold is practicable and might be auspicious, because of subjective feeling of increased intensity (Doermann, 2011).

With regards to the stimulation frequency, a wide range between 2-200 Hz is recommended (Bossert et al., 2006). Comprehensive recommendations for high stimulation intensities range between 50-100 Hz (Filipovic et al., 2011). In addressing the level of impulse width, a compromise needs to be found in order to activate deeper motor units without being unpleasant for the athlete. Longer impulse durations result in deeper and more intensive muscle stimulation, which results in more motor units being recruited (Baker et al., 1993; Bossert et al., 2006). Bossert et al. (2006) recommend a level between 300-400 microseconds due to the unpleasant or even painful sensation above that level. Regarding the stimulation ratio, Filipovic et al. (2011) revealed a predominant use of short impulse on-times of 6.0 ± 2.4 seconds in all EMS methods for enhancing strength abilities. During dynamic exercise, on-times should be synchronized to movement and repetitions.

A number of different studies have documented the positive effects of applying EMS on physical performance parameters such as muscle strength and power (Babault et al., 2007), sprint and jumping performance (Herrero et al., 2006) or anaerobic performance (Herrero et al., 2010b). A review by Filipovic et al. (2012) found that EMS methods are also effective in enhancing maximal strength and power in elite athletes and consequently increasing jumping and sprinting ability. Enhancing performance parameters with the application of EMS training periods from 4-6 weeks, consisting of three sessions per week has been shown to be sufficient (for review see Filipovic et al. (2011)). Most of the previous research has focused on EMS at maximal intensities during isometric contractions in one muscle (group), e.g. the m. quadriceps femoris. Only one study has addressed dynamic movements during EMS or EMS superimposed to leg strength training (Willoughby and Simpson, 1998) with positive effects. Currently, no study has investigated the effects of EMS applied to several muscle groups superimposed to loaded back squat exercise. Superimposed EMS could improve the quality of squat exercise during specific block training phases and increase training adaptations on a high level.

Therefore, the aim of this study was to investigate the effects of a 10 repetition maximum (RM) loaded back squat exercise program with EMS superimposed to several leg and trunk muscles on athletic performance. Athletic performance parameters were differentiated in maximum isometric strength and isoinertial power of several leg and core muscle groups, jump height and sprint time. It is hypothesized that squat training with superimposed EMS will increase strength and power and these improvements will enhance jump and sprint performance more than squat training alone.

Methods

Experimental approach to the problem

Twenty participants undertook a 10 RM loaded squat training program two times per week for six weeks. They were randomly assigned into two groups: Group one (S+E) performed 10 RM loaded squat training with superimposed EMS (n = 10; age: 22.1 ± 1.9 yrs; height: 1.84 ± 0.06 m; mass: 83.7 ± 8.9 kg; lean mass: 74.2 ± 7.7 kg). Group two (S) acted as an active control group with the same training program, but without EMS (n=10; age: 21.9 ± 1.6 yrs; height: 1.84 ± 0.07 m; mass: 78.3 ± 4.4; lean mass: 70.9 ± 4.2 kg).

Measurements of strength, sprinting and jumping abilities took place one week before the training period (pre), one week after the training period (post) and three weeks after the training period as a retest (re).

Subjects

20 male participants between the ages of 20-30 years participated in the study. The participants had a training volume of 3-6 h/week in sprint and jump related disciplines performed at a regional competition level. The disciplines the athletes were trained in were: soccer (6 subjects), fitness (5), combat sports (4), basketball (2), handball (1), badminton (1) and skeleton (1). Furthermore, the participants had experience in resistance exercise (> 2 years) and were experienced in performing back squats. Participants which were unable to complete the 10 RM back squat with acceptable technique and an additional load of at least body weight were excluded from the investigation. Participants were medically examined prior to commencing the study and signed a consent document after being informed about the possible risks and benefits of the study. The study received approval from the Ethical Committee of the German Sport University in Cologne and was conducted in accordance with the Declaration of Helsinki.

Procedures

During the 6-week training period, participants performed 12 training sessions (TS; 2/week) each with 4 sets of squat exercise: set 1 at 50% 10 RM and set 2-4 at 100% 10 RM with a rest time of 120s between each set. Range of motion and velocity were standardized by a biofeedback system (Biofeedback 2.3.1, digimax, Hamm, Germany). A Smith machine was used for safety reasons and to ensure continuity in lifting technique. The additional load for every participant was adjusted to 10 RM if the exercise was no longer exhaustive (at least 16 on a 20-Borg-scale (Borg, 1998)), or when exhaustion was reached before 10 repetitions. Furthermore, intensity of the applied electrical stimulus was matched to 70% of individual pain threshold. This represents an intensity that enables dynamic movement as pre-testing in our laboratory showed (Doermann, 2011).

Two familiarization sessions for testing and training took place one week before the pre diagnostics. During these sessions the testing devices were adjusted individually and the participants were familiarized with the test procedures. Furthermore, the additional load for the 10 RM and EMS intensity were determined.

10 RM Back Half Squat at 90 Degrees

Each participant started in an upright position, looking forward and firmly grasped the bar with both hands. The bar was positioned squarely on the shoulders. The 10 RM were determined as described by Baechle and Earle (2008). Fractional and temporal distribution of the contraction mode (2s eccentric - 1s isometric - 2s concentric - 1s isometric) and range of motion (180° to 90° knee joint) were standardized by a biofeedback system.

EMS

The EMS surface electrodes (miha bodytec, Augsburg, Germany) for the S+E group were applied with a focus on leg and trunk muscles. EMS (belt) electrodes were placed around the muscle belly of the calf muscles (27 cm length x 4 cm height), the thigh muscles (44 x 4 cm), as well as on the buttocks (13 x 10 cm). Additionally, the upper body was stimulated with two bilaterally paired electrodes which are integrated in the stimulation vest at the lower back muscles (14 x 11 cm) and abdominal muscles (23 x 10 cm). The main muscles and muscle groups stimulated were the: m. *triceps surae*, *tibialis anterior*, hamstrings (*semitendinosus*, *semimembranosus*, *biceps femoris*), *quadriceps femoris*, adductors of the legs (*pectineus*, *adductor longus*, *adductor brevis*, *adductor magnus*, *gracilis*), *gluteus maximus*, *erector spinae* and *rectus abdominis*.

The intensity of EMS during the training was adjusted to 70% of the maximal individual pain threshold (maximum tolerated amperage [0-120 mA]). The maximal tolerated amperage was verified separately for each pair of electrodes before each training session. The participants stood in the starting position of the squat while pre-activating their lower limb muscles. The verification of individual pain threshold began with the electrodes at the buttock, followed by the thigh, the lower leg, the abdominal and the lower back electrodes. Subsequently, maximum intensity was verified for simultaneous stimulation of all muscle groups and then adjusted to an intensity of 70% to enable dynamic movements. Impulse frequency was set at 85 Hz, pulse duration at 350 µs, type was bipolar and rectangle with an on/off-ratio of 5/1 s. On/off-time was synchronized with a biofeedback system. Off-time was synchronized to standing position (1s). On-time was synchronized to eccentric (2s), isometric (1s) and concentric (2s) contraction mode with simultaneous stimulation to all stimulated muscle groups. The training intensity of each set was controlled by the Borg-scale and set to > 16 (> “hard”).

Testing Procedures

The pre-, post- and re-tests took place one week before (pre), one (post) and three weeks (re) after the 6-week training period. The tests were conducted at different days in the same order: 1) sprint and jump tests 2) strength and power diagnostics.

Day 1

Countermovement jump: For the evaluation of the maximal jump abilities three trials of a squat jump (SJ) and a countermovement jump (CMJ) were conducted. For the CMJ the participants were instructed to begin from a standing position followed by a reactive maximal vertical jump. For the SJ the participants were instructed to begin from a squat position followed by a non-reactive maximal vertical jump. The jump with the greatest height for each variation was subsequently used for analysis. Hands remained on the hips for the entire movement of each jump for both jump variations to eliminate any influence of the arm swing. Jumping performance was measured with the Optojump system (Microgate, Bolzano, Italy).

Sprint performance: The two following sprint performance tests were conducted. A linear 30m sprint and a pendulum sprint of 3 x 10m with two direction changes of 180° (at 10m and 20m) with the final time measured at 30m. Starting position was 50cm before to the start light beam for both sprint tests. Participants had two minutes recovery between the trials. Double infrared photoelectric barriers with a radio transmitter (DLS/F03, Sportronic, Leutenbach-Nellmersbach, Germany) were used for time measurement. The faster time of two trials per sprint variation was used for subsequent analysis.

Day 2

Strength diagnostics: Isometric strength and isoinertial power diagnostics took place on leg curl (LC) and leg press (LP) machines, as well as isometric strength diagnostics on abdominal press (AP) and back extension (BE) machines (Edition-Line, gym80, Gelsenkirchen, Germany). The machines were equipped with the digital measurement technique Digimax (mechaTronic; Hamm, Germany). This allowed measurements of force-time and velocity-time variables (5 kN strength sensor typ KM1506, distance sensor typ S501D, megaTron; Munich, Germany) with the software IsoTest and DynamicTest 2.0. The sensors were installed in line with the steel band of the machines that lifts the selected weight plates. Maximum Force relative to body weight (Frel [$N \cdot kg^{-1}$]: highest value of force-time curve divided by body weight) and maximum Power relative to body weight (Prel [$W \cdot kg^{-1}$]: highest product of force [N] and velocity [$m \cdot s^{-1}$] of power-time curve divided by body weight) were calculated for statistical analysis and data presentation.

Diagnostic procedures for leg machines (LC and LP) consisted of three isometric and three isoinertial tests to measure maximal strength and power, respectively. Isometric attempts were conducted at an inner knee angle of 120° on LP and of 160° on LC. The additional load for the isoinertial tests was calculated individually as a percentage of the maximal isometric strength attempted in an additional isometric test with the same angle as the starting position of the isoinertial test (LP 90°; LC 170°). Three attempts were conducted with 40% additional load on LC and with 50% additional load on LP. The three isometric strength tests on the trunk machines (AP, BE) were conducted at a hip angle of 90°. The instruction for isometric tests was to press as fast and as forcefully as possible against the fixed lever arm. This was in order to determine joint angle-dependent force-time curve during explosive maximum. The same procedure was instructed for the isoinertial tests in order to examine joint angle-dependent power-load curve, during explosive maximum voluntary leg extension (LP) or knee flexion (LC) over concentric ROM (inner knee ROM: LP 90-180°; LC 170-80°).

Statistical analysis

All data was analyzed with STATISTICA (version 9, StatSoft, Inc., Tulsa, USA). Pre-, post- and re-test data was compared using ANOVA repeated measures [group (S; S+E) x time (pre-; post-; re-test)] with Fisher post-hoc test. P<0.05 was considered significant.

Effect size Cohen's *d*, defined as difference in means/standard deviation was calculated for groups between pre- vs. post-test and pre- vs. re-test. Thresholds for small, medium, and large effects were 0.20, 0.50, and 0.80, respectively (Cohen, 1988).

Reliability was determined by the coefficient of variation (CV) and the intraclass correlation coefficient (ICC) for parameters force (F) (CV < 8%; ICC 0.95-0.97), as well as for power (P) and power factors (F·V) (CV < 9%; ICC 0.84-0.97) for all used machines (Doermann, 2011). Sprint running performance tests (*linear* and *change of direction*) were shown as highly relative reliable (CV 1-6%; ICC 0.80-0.96) (Green et al., 2011), as well as Optojump based jump height (CV < 3% and ICC > 0.9) (Glatthorn et al., 2011).

Results

The body mass and lean body mass of the two groups did not change over the training period. Results for the training characteristics and performance measurements are presented in Tables 1-3. No significant differences in pre values could be found between groups. Load was increased significant from TS 1 to TS 12 for both groups (p < 0.001). Furthermore, electrical stimulus intensity was enhanced significantly for S+E group from TS 1 to TS 12 (p < 0.001; Table 1).

Strength and power parameter

Differences between groups were only evident at the LC machine with greater improvements for the S+E group. Interaction effects (group x time) at LC machine was found for F_{rel} (p = 0.047) and P_{rel} (p = 0.046). Post-hoc analysis of F_{rel} showed significant improvements only for S+E at re-test (p = 0.005), but not at post-test (p=0.052) in comparison to pre-test. Furthermore, significant differences between groups at re-test (p = 0.003) were evident. Analysis of P_{rel} showed significant improvements for S+E at post-test (p = 0.001), however, not at re-test (p = 0.059) in comparison to pre-test (Table 3). At LP both groups improved. No group or interaction effects could be found, but time effects for F_{rel} and P_{rel} (F_{rel}: p<0.001; P_{rel}: p = 0.019). Post-hoc analysis showed significant improvements at post- and re-test in comparison to pre-test for both groups (p < 0.01). At BE, no group or interaction effects, but time effects could be found for F_{rel} (only F_{rel}: p = 0.005). Post-hoc analysis showed significant improvements at post- and re-test in comparison to pre-test for both groups (p < 0.02). No effects could be observed at AP (Table 2).

Sprint time

For linear sprint time (30m), no effects in time (p = 0.43), group (p = 0.41) or interaction (p = 0.39) were found. Pendulum sprint (3x10m) improved for both groups. No group or interaction effects, but time effects (p < 0.001) could be found. Post-hoc analysis showed significant improvements at post- and re-test in comparison to pre-test for both groups (p < 0.01) (Table 3).

Jump height

SJ and CMJ height improved for both groups. For SJ

Table 1. Parameter of training intensity at training session 1 (TS 1) and training session 12 (TS 12). Data are means (±SD).

Parameter	Group	TS 1	TS 12	% Delta TS 1-12	Cohen's d TS 1:12
Additional load (kg)	S+E	91.5 (12.5)	106.5 (15.7) *	+ 16.4	1.06
	S	85.0 (11.4)	97.75 (15.9) *	+ 15.0	.92
EMS intensity (arbitrary units)	S+E	28.3 (5.0)	33.8 (5.8) *	+ 19.6	1.02

* indicates significant differences to pre (p < 0.05). Groups: S (strength); S+E (strength + EMS).

Table 2. Results for strength and power (F_{rel}; P_{rel}) for the Leg Press (LP), Leg Curl (LC), Abdominal Press (AP) and Back Extension (BE) for both groups at 1 week before intervention (pre-test), 1 week after intervention (post-test), and 3 weeks after intervention (re-test). Data are means (±SD).

	Parameter	Group	pre-test	post-test	re-test	Cohen's d (pre-post)	Cohen's d (pre-re)
LP	F_{rel} (N·kg^{-1})	S+E	50.4 (3.3)	63.3 (13.6) *	64.8 (8.8) *	1.30	2.16
		S	48.1 (11.1)	57.8 (16.6) *	61.8 (20.6) *	.69	.83
	P_{rel} (W·kg^{-1})	S+E	21.1 (3.6)	22.3 (3.7)	23.1 (4.5) *	.35	.50
		S	19.6 (4.7)	19.5 (4.6)	21.0 (4.5) *	.02	.31
LC	F_{rel} (N·kg^{-1})	S+E	18.0 (1.5)	19.0 (1.5)	19.5 (1.5) * †	.69	1.05
		S	15.7 (3.3)	16.5 (2.5)	15.8 (2.3) †	.27	.04
	P_{rel} (W·kg^{-1})	S+E	9.8 (1.1)	10.9 (1.5) *	10.5 (1.3)	.85	.50
		S	9.1 (2.0)	9.1 (1.7)	9.3 (2.1)	.01	.14
AP	F_{rel} (N·kg^{-1})	S+E	12.6 (1.4)	12.2 (1.4)	12.5 (1.1)	.25	.06
		S	11.9 (1.8)	11.6 (1.6)	12.1 (1.1)	.17	.11
BE	F_{rel} (N·kg^{-1})	S+E	18.4 (4.8)	21.3 (4.8) *	22.4 (5.0) *	.59	.81
		S	18.7 (6.0)	20.2 (6.1) *	20.4 (5.1) *	.26	.31

* indicates significant differences to pre; † indicates significant differences between groups (p < 0.05). Groups: S (strength); S+E (strength + EMS).

Table 3. Results for sprints (linear 30m; pendulum 3x10m) and jumps (SJ; CMJ) for both groups at 1 week before intervention (pre-test), 1 week after intervention (post-test), and 3 weeks after intervention (re-test). Data are means (±SD).

	Parameter	Group	pre-test	post-test	re-test	Cohen's d (pre-post)	Cohen's d (pre-re)
sprints	linear 30m (s)	S+E	4.21 (.09)	4.24 (.11)	4.24 (.09)	.30	.33
		S	4.28 (.17)	4.26 (.16)	4.30 (.17)	.12	.12
	pendulum 3x10m (s)	S+E	7.52 (.18)	7.40 (.20) *	7.34 (.20) *	.63	.95
		S	7.55 (.19)	7.40 (.21) *	7.47 (.18) *	.75	.43
jumps	SJ (cm)	S+E	34.6 (2.1)	36.01 (3.3) *	37.6 (5.2) *	.50	.75
		S	34.9 (4.9)	38.27 (4.7) *	40.3 (5.8) *	.70	.99
	CMJ (cm)	S+E	38.4 (3.1)	40.4 (3.7) *	41.1 (4.4) *	.58	.70
		S	39.3 (5.6)	42.4 (5.9) *	43.0 (5.3) *	.54	.68

* indicates significant differences to pre ($p < 0.05$); Groups: S (strength); S+E (strength + EMS).

height, ANOVA showed no group or interaction effects, but time effects ($p < 0.001$). Post-hoc analysis showed significant improvements at post- and re-test in comparison to pre-test for both groups ($p < 0.01$). For CMJ height, ANOVA showed no group or interaction effects, but time effects ($p < 0.001$). Post-hoc analysis showed significant improvements at post- and re-test in comparison to pre-test for both groups ($p < 0.01$) (Table 3).

Discussion

This study investigated the effects of superimposed EMS during six weeks of 10 RM squat exercise training on strength and power of several leg and trunk muscles as well as on physical performance. It was hypothesized that squat training with superimposed EMS will increase strength and power, jump, and sprint performance more than squat training alone. The main results of this study were: 1) Both training groups increased their 10 RM significantly, throughout the six week training program (S: +15%; S+E: +16%, $p < 0.05$). 2) The electrical stimulus intensity in the S+E group increased significantly over the training period (+20%). 3) Similar strength adaptations for both training groups with specific adaptations for S+E at the leg curl muscles were evident. 4) Both groups improved SJ, CMJ and pendulum sprint performance significantly, without significant differences between the groups. 5) No improvement occurred in linear sprint performance.

Frel in LP improved considerably for both groups after the training period, with medium to large effect sizes at post- and re-test. This result is reasonable, since LP was the most specific strength test machine compared to the squats during the training period. S+E showed even larger effect sizes on LP strength improvements ($d = 1.3$ (pre to post); $d = 2.2$ (post to re)) than S ($d = 0.7$; 0.8, respectively); However, there were no significant differences between both groups in Frel at LP after the intervention period. Improvement in strength could be transferred in maximal isoinertial movement, as shown by the improvements in Prel. Prel and Frel both showed a lag effect. Prel improved significantly for both groups not before the retest, without differences between both groups. Frel in LP even showed further improvements for re- in comparison to the post-test, however this was not significant. With regard to lack of significant differences between groups, we cannot confirm the hypothesis that strength training with superimposed EMS improves strength more than strength training alone. However, due to the different effect sizes of Frel we finally cannot refuse the hypothesis. Another study also suggests that supplementing the strength training induced voluntary contractions with superimposed EMS at concentric and eccentric phases has a significant positive impact for improving muscular strength (Willoughby and Simpson, 1998). Interventions of other studies compare strength training and EMS without superimposed use. Requena Sanchez et al. (2005) summarized, that strength gains induced by EMS alone (i.e. without additional strength training) could be as large as, but not greater than voluntary contractions without EMS. Large increases in isometric strength after EMS training periods (of 4-8 weeks) suggest dependence on an increase in activation of the stimulated muscles, possibly due to an increase in the quantity of the neural drive to muscle from the supraspinal centers (Colson et al., 2000; Moritani and deVries, 1979). A further explanation is due to changes at a peripheral level through preferential adaptations of the type II fibers (Maffiuletti et al., 2002). For the present study it can be speculated that because of the quite high intensity during the 10 RM, many of the muscle fibers in leg and hip extension muscles were already activated and consequently no more additional muscle fibers have been activated by superimposed EMS.

Frel of other muscle groups which are involved during squat exercise showed different results. No adaptations could be observed in AP for both groups, but there were improvements in Frel in BE for both groups without significant differences between the groups. Although trunk muscles are working isometrically during squats, activation depends on the load only for BE, but not for AP muscles (Hamlyn et al., 2007). In congruence, improvements of BE occured in both groups depending only on the additional load and not on EMS. However, little differences can be seen as Frel of BE shows higher effect sizes for S+E ($d = 0.6$-0.8) than for S (0.3). These little differences could be attributed to a force deficit correction because of superimposed EMS. Furthermore, force deficit corrections would rather be expected in less activated muscle groups like AP muscles. However, results do not show strength adaptations at the AP for S+E. The combination of EMS and volitional exercise was determined to be effective for isometric strength gains of the abdominal musculature by local maximum stimulation at subjects with low training status (Alon et al., 1987). One possible reason for the smaller improvement in the present study is a higher training status of the participants than in the study by Alon et al. (1987). Another reason can be the lower EMS intensity in the present study, because EMS is applied on a submaximal intensity and superimposed to several muscle groups during complex movement without abdominal muscles in focus of movement.

However, there were EMS-specific adaptations in the hamstrings (LC) which have also stabilizing functions during dynamic movements. LC was the only tested muscle group that showed EMS-specific improvements in Frel and Prel. Differences between groups were at re-test for Frel. Furthermore, significant improvements for Frel were only evident for S+E with large effect sizes (Cohen´s d: 0.7-1.1). These different adaptations occurred, although the baseline of LC strength was even higher for S+E. For Prel significant improvements were shown at post-test only for S+E. Potentially the activation of the hamstrings during squats was higher with EMS, because less voluntary activation of antagonistic than agonistic working muscles during loaded squat exercise is evident (McCaw and Melrose, 1999). Furthermore, in contrast to AP or BE muscle groups, motor control of hamstrings has to be adapted to the EMS-induced resistance during eccentric and concentric contraction modes. These results give space for speculation of beneficial adaptations of EMS to particularly antagonistic working muscles during movement pattern. Although, one might expect a counterproductive effect of whole body EMS by simultaneous stimulation of agonistic and antagonistic working muscles, the counterproductive activation might not be of consequence for handling the additional load. This is because of the quite low force production of about 25% of maximum voluntary contraction caused by EMS stimulation even for maximum intensity at pain threshold (Hortobagyi et al., 1992; Jubeau et al., 2008).

The strength gains of sprint relevant muscle groups did not show carry-over effects in linear sprint performance. In line with the present results, linear sprint performance did not improve in other EMS studies, too (Babault et al., 2007; Herrero et al., 2010a; Herrero et al., 2010b). Studies that enhance linear sprint performance used EMS in combination with sport/sprint specific or plyometric training (Brocherie et al., 2005; Herrero et al., 2006; 2010a; Voelzke et al., 2012). However, plyometrics seem to be an important attribute to carry over strength gains to linear sprint performance (Herrero et al., 2006; 2010a). Furthermore, utilization of complex movements seems to be important. A study by Brocherie et al. (2005) showed enhanced 10m sprint skating time using EMS over a three week period (3 times a week) in 2nd league ice-hockey players. The m. quadriceps femoris was stimulated at individual maximum tolerated intensity and consisted in various short isometric contractions. In the present intervention no explosive contractions like jumps or plyometrics were conducted and no specific training for linear sprint took place. We only can speculate that specific training programs of sprint and explosive contractions could have carried-over strength gains to linear sprint performance. In congruence to our results, Kotzamanidis et al. (2005) also reported a lack of transferring strength gains to jump and running performance when squat training is conducted without any specific sprint or jump training.

Nevertheless, pendulum sprint performance with two changes in direction was enhanced significantly, with medium to large effects for both groups. Due to the review of Sheppard and Young (2006), sprinting and agility are separate physical qualities with a weak relationship between linear sprint and change of direction speed performance. A study of Maffiuletti et al. (2009) showed congruent results. Subjects decreased their shuttle run time after an isometric EMS training program of the m. quadriceps femoris at maximum pain threshold during nine sessions in three weeks. It has to be considered that the isometric EMS intervention was incorporated into on-court skill training and match play of competitive tennis players during preseason preparation. However, no additional functional drills for motor control or coordination were part of the present intervention. Nevertheless, both training groups improved pendulum sprint time. One explanation could be an improved ability of simultaneous deceleration and acceleration in the knee and hip extensor muscles, which is also demanded during squat exercise. This could also explain the improvements in SJ and CMJ for both groups. Several studies show that back squat exercise represents a sufficient training stimulus for enhancing vertical jump performance (Chelly et al., 2009; Cormie et al., 2010; Wilson et al., 1993). Combining methods did not reach further effects than observed in literature. Both strength training and EMS with combined plyometrics are examined to enhance jump performance in similar amount (3-18%), but not EMS alone (Perez-Gomez and Calbet, 2013). Furthermore EMS training combined with basketball (Maffiuletti et al., 2000) or volleyball training (Malatesta et al., 2003; Voelzke et al., 2012) led to benefits on vertical jump performance.

Nevertheless, superimposed EMS could be taken under consideration for prevention of muscle injuries, due to the adaptations of the hamstrings. Hamstring strains are the most prevalent muscle injuries reported in different team and sprint related sports and can be prevented by e.g. eccentric hamstring strengthening as by the use of EMS (Goode et al., 2015). The present results suggest that the use of EMS is a good possibility to strengthen the hamstrings.

Practical application

Adaptations to back squat exercise are primarily improvements in maximum strength abilities of leg and hip extensors, accompanied by improvements in jumping abilities. No improvements can be expected for linear sprint performance without specific training programs. Superimposed EMS and back squat exercise do not lead to higher adaptations of strength and performance abilities than loaded back squat exercise alone. However, superimposed EMS on several muscle groups during squats affects adaptations in antagonistic hamstrings, suggesting the potential of unloaded dynamic EMS on strength abilities. Furthermore, these specific adaptations might be beneficial with regard to hamstring muscle injuries.

Conclusion

In conclusion, this study shows that common strength training and strength training with superimposed EMS both enhance strength of knee and hip extensors, as well as jumping and pendulum sprint performance without improvements in linear sprint performance. However, improvements of antagonistic hamstring strength in the S+E group suggest the potential of EMS to unloaded (antagonistic) muscle groups during training. Future research should seek to establish if superimposed EMS during complex movements like sprint and jump exercises could be a possible method to achieve positive effects for sport specific performance.

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Key points

- Similar strength adaptations occurred after a 6 week 10 RM back squat exercise program with superimposed EMS (S+E) and 10 RM back squat exercise (S) alone.
- Specific adaptations for S+E at the leg curl muscles were evident.
- S and S+E improved SJ, CMJ and pendulum sprint performance.
- No improvement occurred in linear sprint performance.

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