Effects of Two WB-EMS Programs and Resistance Circuit Training on Strength and Power

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Abstract

The main purpose of this study was to compare the effects on strength and muscle power of a training program based on two different modalities of whole-body electrostimulation (WBEMS) with respect to a resistance-training program aimed at improving dynamic strength. Twenty-two subjects participated in this study: Thirteen male (age 25.2 ± 2.8 years; height 1.78 ± 0.1 m; body mass 72.8 ± 6.4 kg; body fat 11.6 ± 2.3 %) and nine female (age 28.2 ± 3.5 years; height 1.63 ± 0.05 m; body mass 56.8 ± 7.6 kg; body fat 19.1 ± 4.7 %). Participants were randomly assigned to three groups that underwent three different 6-week training programs: two modalities of WB-EMS, based on different electrical parameters (experimental), and circuit training with overloads (control). Force-velocity curves were calculated for each participant before and after treatment. All groups improved their level of strength and muscle power (paired sample t-Test, $p < 0.01$; $d > 1$) with a similar magnitude. No significant differences were observed between groups (two-way 2 × 3 Anova, $p > 0.05$) at the end of the experimentation. This study suggests that WB-EMS might be considered as a valid and faster alternative – or an important complementary procedure – to a traditional overload-based resistance-training program for the development of the DS.

Introduction

Background

Electrical muscle stimulation (EMS) consists of local application of an electric current to elicit a muscle contraction [1]; in sports training, the most commonly used technique is percutaneous electrical stimulation, where the electrostimulation is applied to the muscular belly [2]. Several studies performed both in the medical and sports fields have extensively analyzed the principles and the parameters of the EMS [mainly considering the intensity of the electrical stimulus (Amp), the frequency (Hz), and the width of the impulse] and the physiological adaptations to the EMS training [3–12, 27].

Certainly, fewer studies have taken into account whole-body electromyostimulation (WB-EMS), a training method associated with a voluntary pre-contraction both isometric or dynamic [10, 13].

The WB-EMS is a technique that can stimulate various muscle groups simultaneously by the means of special suits fitted with multiple electrodes. As reported in the literature, with this technique it is clearly possible to obtain improvements in strength and muscular power, body composition [14], physical performance such as jumping ability and sprinting [15, 16], and in the specific technical skills of some sports disciplines [17]. However, it remains unclear whether electrical stimulation and voluntary muscle contraction can be considered as complementary stimuli of different nature from the physiological point of view, due to the different recruitment patterns: In electrostimulation, larger motor units might be recruited before the smaller motor units, exactly the opposite of what happens in a voluntary contraction, according to Henneman's Size Principle. It is now also demonstrated that the effects of training with the WB-EMS method consist of positive adaptations that directly affect the performance of healthy subjects or athletes [14, 17].

Recently, the study by Micke et al. [7] has shown that a WB-EMS program provides similar improvements, compared to a traditional training program, in terms of maximal isometric strength (Fmax) and maximal isoinertial power (Pmax) for the leg muscles, measured through the leg extension (LE), leg curl (LC), and leg press (LP) machines, of jumping performances, measured by the means of squat jump (SJ), counter movement jump (CMJ), drop jump (DJ) and standing long jump (SLJ), of sprinting abilities measured through linear (30 m) and shuttle sprinting (3 x10 m).

Aims

The purpose of this study was to assess the effects of a 6-week training program on strength and muscle power of upper and lower limbs, using a WB-EMS training with two different intensity protocols [9], compared to a traditional resistance-training program with overloads. Strength and muscle power were measured and assessed in the 3 groups before and after treatment in comparable conditions, through the estimation of the relevant force-velocity curves, so to obtain information on the different possible adaptations of the force expressions, ranging from maximal strength to explosive power.

The novelty of our study was represented by the assessing procedures that gave us a broader insight from what was currently available in the scientific literature about the mechanics of muscle contraction.

Materials and Methods

Experimental approach to the problem

Participants were randomly assigned to 3 different groups: one control group (CT-DS, n = 8) and two experimental ones (WB-EMS1, n = 6; WB-EMS2, n = 8).

Three distinct phases were arranged:

1. Initial testing, carried out in the week prior to the experimental phase and aimed at measuring the baseline levels of some physical parameters (anthropometric data, values of strength and power of the upper and lower limbs in order to define the relevant force-velocity curves); after that, the participants were randomly assigned to the different training (treatment) groups.
2. Administration of different treatments, consisting of:

a. Circuit Training – Dynamic Strength (CT-DS)

b. Whole Body Electro-stimulation – protocol 1 (WB-EMS1)

c. Whole Body Electro-stimulation – protocol 2 (WB-EMS2)

In this study we decided to verify the effect of two different stimulus frequencies (i. e. 50 vs. 85 Hz – see ▶**Table 2**) induced by two different WB-EMS protocols, as already proposed in other researches [8]. According to Paillard et al. [8] WB-EMS protocol 1, based on a frequency of 50 Hz, is to be included in the most efficient methods for the development of muscle strength. WB-EMS protocol 2, based on a frequency of 85 Hz, could instead have strong inhibitory effects on muscle contraction and induce afferent signals including a possible nociceptive component.

3. Final testing, designed to measure the changes in the neuromuscular status (dependent variables) induced by the different types of treatment (independent variables) and carried out in the week after the experimental phase.

Subjects

Twenty-two subjects participated in this study: thirteen male (n = 13; age 25.2 ± 2.8 years; height 1.78 ± 0.1 m; body mass 72.8 ± 6.4 kg; body fat 11.6 ± 2.3 %) and nine female (n = 9; age 28.2 ± 3.5 years; height 1.63 ± 0.05 m; body mass 56.8 ± 7.6 kg; body fat 19.1 ± 4.7 %).

The sample consisted of students of Physical Education (n = 22) – Faculty of Medicine and Surgery – University of Rome "Tor Vergata," who usually performed at least three training sessions per week, mostly soccer, thus holding a medium-high fitness status. Written informed consent was obtained from all the participants after familiarization and explanation of the benefits and risks involved in the procedures of this study. All participants were informed that they were free to withdraw from the study at any time without penalty. The Institutional Research Board (Ethical Committee of the School of Sports and Exercise Sciences, University of Rome "Tor Vergata", Faculty of Medicine and Surgery) approved our research protocol and provided clearance for the procedures before the commencement of this study. All procedures were carried out in accordance with the Declaration of Helsinki (1975, revised in 2013) of the World Medical Association as regards the conduct of clinical research. We confirm that we have read and understood the IJSM's ethical standards document [18] and that this study meets the ethical standards of the journal.

Before undergoing test procedures, all participants were required to provide a certificate of medical fitness, excluding pathologies and contraindications to high-intensity physical activities and treatments based on electrostimulations.

Procedures

All the experimentation took place at the Human Performance and Training Laboratory “Carmelo Bosco” – University of Rome “Tor Vergata”.

In the week prior to the experimentation, assessment testing with increasing overloads to determine the initial force-velocity curve for all the participants was administered. To do so, the barbell bench press and squats on the Smith machine were used. The value of 1-RM has been calculated for each participant applying the formula suggested by Brzycki [19].

To draw the velocity-force curve, we considered the four loads described in ▶**Table 1**, obtained as percentages of the previously calculated 1-RM, both for the upper limbs loads (barbell bench press) and for the lower limbs (squatting at the Smith Machine), for both males and females.

After that, the participants were randomly split into the three groups. Then the research protocol started, including 12 training sessions carried out over 6 weeks.

The first group (CT-DS) performed circuit training in the gym aimed at improving dynamic strength (DS), using overloads. Circuit training comprised the following exercises: barbell bench press, dumbbell biceps curl, lat pulldown, prone plank (with no overload), squatting (using the Smith machine), prone leg curl, standing calf.

Ten repetitions were performed for three sets consecutively for each exercise with a load equal to 65 % of one repetition maximum (1-RM). Resting time among series was 1 min and 30 s. A fitness coach personally followed the participants of the CT-DS group, supervising the whole training session.

The second (WB-EMS1) and the third group (WB-EMS2) performed the whole-body electro muscle stimulation (WB-EMS) training according to the electrical and methodological parameters described in ▶**Table 2**.

During the WB-EMS treatments, each participant was asked to perform, exactly at the start of the impulse, the following set of ten isometric exercises (2 min per exercise), without any machine or external loads: abdominal cross crunches, ¼ squat and abdominal crunch, ½ squat and pectoral exercise, ½ squat and arms extension, ½ squat and reverse butterfly, ½ squat and lat exercise, ½ squat and biceps curl, ½ squat and triceps push down, ½ squat, forward lunges.

In order to obtain the force-velocity curves (▶Figs. 2– 5) after the training period, a new testing phase was implemented in the week following the end of experimentation, in order to evaluate the physical effects of the different treatments on the muscle strength and power. To assess the possible increases, considered at the various loading levels (%), participants were tested with the same loads used in the initial tests, thus maintaining the same loads to be accelerated.

Instrumentation

To determine the force-velocity curves, a Gyco accelerometer (Microgate, Bolzano, Italy, 2015) with a 1000 Hz sampling frequency was used. As for the training with WB-EMS (XBody, Actiwave, Győr, Hungary), subjects wore a special gym suit fitted with multiple electrodes, (provided by Urban Fitness, Milan, Italy – ▶Fig. 1), which simultaneously stimulated the following muscle groups: brachial biceps, brachial tricepses, trapezius, dorsal muscles, pectorals, abductors, gluteus maximus, femoral quadriceps and femoral biceps. The gym suit was carefully wetted to allow the best electrical behavior of the device and consequently the best performance during the training session lasting 20 min. The CT-DS training group performed physical exercises that solicited the same muscular districts through the use of conventional gym equipment such as dumbbells, barbells and iso-inertial machines.

On experimentation days, the lab setting was arranged in two dedicated areas to carry out the circuit training with the overloads and the session of WB-EMS training: The two activities were performed at the same time and with a continuous assistance from the researchers involved in this study.

Statistical analyses

Data are presented as mean ± SD and confidence intervals (95 % CIs) for the means of the differences of the pre-post testing.

The assumption of normality was assessed using the Shapiro- Wilk test.

The Intraclass Correlation Coefficients (ICC) for average measure are provided as indices of relative reliability of the tests.

To test the differences before and after the treatments (withineffects) the t-Test for paired samples was performed. Effect Size (ES) indicators as Cohen's d were provided and they were computed according to the formula $d = t/ n$ [26], where t = paired sample t-Test value and n = number of observations. Absolute ES of 0.20, 0.50, 0.80, > 1 represent small, medium, large and huge effects, respectively.

To point out the possible differences among groups (between) – pre and post the administration of the treatments – a two-way analysis of variance [2 (pre and post treatment) × 3 (control and the two experimental conditions)] was used to determine possible main effects or interactions and, if so, to compare the significant differences among the three groups. Effect Size (ES) in ANOVA was computed as partial η2, to assess meaningfulness of differences, with $\eta 2 < 0.01$, $0.01 < \eta 2 < 0.06$, $0.06 < \eta 2 < 0.14$ and $\eta 2 > 0.14$, as trivial, small, moderate and large ES, respectively.

A post hoc power analysis was used to verify whether a sample size of 22 subjects, assigned in three groups, was sufficient to detect the effect of the interventions on the force and power results, based on the observed pre- and post-treatment mean values and SDs. It suggested that the data could be interpreted with a large to very large effect size (ES) level, ranging from 2.71 ± 1.07, 2.96 ± 1.19, 2.49 ± 0.73 and 1.94 ± 0.37 (mean ± standard deviation) and power levels > 0.95 when significance was set at an alpha level of 0.05, for squatting tests, force and power values and bench press tests, force and power values, respectively.

The corresponding P values are provided for each analysis. The value of statistical significance was accepted with $P \leq 0.05$. SPSS 20.0 for Windows was used to analyze and process the collected data.

Results

As a measure of the relative reliability of measurements obtained during the testing procedures, the intraclass correlation coefficients were computed for all the observations collected, before and after the different treatments (**Table 3** and **4**).

Squatting testing carried out before and after treatments: Force and Power

Force-velocity curves, drawn before and after the treatments are provided in **Figs. 2– 4**.

The descriptive statistics [mean ± standard deviation, incremental percentages of the differences (Δ), confidence interval for the differences (95 %)] and the relevant values (t; degrees of freedom, p-values and Cohen's d as effect size estimators) of the paired sample t-tests performed to investigate the within effects of the treatments, both for the force values (N) and the power ones

(W) are provided in **Tables 5** and **6**. These results highlighted the large within-effects obtained by all the different treatments considered on the participants ($p < 0.01$; $d > 1$) and achieved during the time of experimentation. These finding are also evidenced by the 2 x 3 two-way ANOVA (within effect) that we performed with very large effect sizes (**Tables 7** and **8**).
The between-group differences (before and after the treatments), both for the force values (N) and power values (W) were verified through the two-way analysis of variance (ANOVA). The relevant results are provided in **Tables 7** and **8**. The effect sizes, estimated as partial eta squared values, are considered. According to these statistical analyses, no evident differences ($p > 0.05$) were found between the different treatments, highlighting the substantial parity of the effects induced by the training modes adopted in this study. We observed some interactions too, suggesting possible slight differences between the groups but a post hoc analysis with Bonferroni correction did not reveal any significant differences ($p > 0.05$).

Barbell bench press Testing carried out before and after treatments: Force and Power
Force-velocity curves, drawn before and after the treatments are provided in **Figs. 4** and **5**.
The descriptive statistics [mean ± standard deviation, incremental percentages of the differences (Δ), confidence interval for the differences (95 %)] and the relevant values (t; degrees of freedom, p-values and Cohen's d as effect size estimators) of the paired sample t-tests performed to investigate the within effects of the treatments, both for the force values (N) and the power ones (W) are provided in **Tables 9** and **10**. These results highlighted the large within effects obtained by all the different considered treatments on the participants ($p < 0.01$; $d > 1$), achieved during the time of the experimentation. These finding is also evidenced by the 2 x 3 twoway ANOVA (within effect) we performed with very large effect sizes (**Tables 11** and **12**).
The between-group differences (before and after the treatments), both for the force values (N) and power values (W) were verified through the two-way analysis of variance (ANOVA). The relevant results are provided in **Tables 11** and **12**. The effect sizes, estimated as partial eta squared values, are considered. According to these statistical analyses no evident differences ($p > 0.05$) were found between the different treatments, highlighting the substantial parity of the effects induced by the training modes adopted in this study. We observed some interactions too, suggesting of possible slight differences between the groups but a post hoc analysis with Bonferroni correction did not confirm any significant differences ($p > 0.05$).

Discussion

This is the first study, to our knowledge, to assess the effects of WBEMS on the whole-muscle capacity using force-velocity curves [25]; the study thus investigates the complex of neuromuscular adaptations induced by this treatment.
The results of the current study showed that 6 weeks of WB-EMS protocol compared to a traditional resistance training with overloads did not lead to significant differences in outcomes. The three training programs, in other words, provide similar results in terms of efficacy of response at the end of the experimental session. These results are in agreement with those reported by Kemmler et al. [14] and Micke et al. [7], confirming the possible alternative or contributive use of the WB-

EMS methods to the efficient training of strength and power. In particular, with respect to the study by Micke et al. (2018), which focused on the strength and power parameters of the leg muscles, our study added new findings investigating the effects of WB-EMS programs on strength and power parameters of upper and lower limbs using force-velocity curves as suggested by Bosco and Komi [20], Bosco [21], and Zatsiorsky and Kraemer [22]. In particular, ▶**Figs 2– 5** indicate the right shift of the entire curves, after the three treatments, demonstrating that both the area of force and that of velocity have increased in a similar way, thus causing harmonics adaptations in all the expressions of muscular force we considered [23]. The wide and harmonic variations of the neuromuscular status observed in all the points of the curves, confirmed by the large effect size values found ($d > 1$), show the adaptations of both fast and slow fibers to the electric stimulus, despite a period of training of only 6 weeks and training sessions lasting only 20 min. As can be seen in ▶**Tables 5, 6 , 9** and **10**, the post-treatment increase is very evident both in the squat and bench press tests, as confirmed by the high percentage increase values reported, for both the expressions of force (range of increase: 2.55– 14.99 %) and power (7.29–22.13 %). All data processing shown in the pre-post treatment comparisons show very high statistical significance ($p < 0.001$) and large effect size.

Observing the different behavior of the post-treatment variations in the values of force and power, the latter varies more widely. This allows us to hypothesize a higher involvement of the fast fibers compared to the slow ones [24]. The fact that the improvements observed after the three treatments are similar is evidenced by the analysis of the variance performed, which shows rather high p values ($p > 0.05$). Indeed, there are no significant differences between treatments except for some effect size values ($\eta 2$ part > 0.14, see ▶**Tables 7**, **8**, **11** and **12**). This allows us to state that the treatments, although similar in the recorded effects, are not perfectly superimposable. Considering the data reported in the graphs and in the Tables, a trend is observed for the WB-EMS treatments that appear a bit more effective, as indicated by the effect size (Cohen’s d), of the first protocol (WB-EMS1) compared to the other two.

All the treatments considered were effective, showing an increase ($p < 0.01$; $d > 1$) of strength and muscle power, which were the physical parameters chosen as indicators of muscle performance. The force-velocity curves calculated before and after treatment, indicated a harmonic growth of the force-velocity curves’ loading parameters, for each training session considered. Thus our attention might focus on the managing aspect of these means of training, underlining the evident time-saving made possible by WBEMS, whose training sessions usually last 20 min, compared to the traditional ones, lasting in average more than an hour.

The training sessions we designed were quite demanding, especially for the WB-EMS1 and the CT-DS. With regard to WB-EMS2, we adopted the manufacture’s guidelines, particularly designed for a broader population of possible users.

The efficacy of the different training sessions suggests that these approaches can be used in different populations with a high level of fitness or in non-athletic customers, as the WB-EMS2 protocol was judged by the participants to be a method without “annoying sensations.” In addition, WB-EMS training is useful for people who want to keep a high level of muscle fitness in a short time. In fact, in this study the participants have spent only 4 h in electrostimula- tion (≈ 20 min × 12 sessions) in twelve training sessions, compared to about 14 h spent in traditional training (≈ 70 min × 12 sessions). Finally, the WB-EMS training can be useful for people who cannot train with loads because of impairments such as arthritis, cartilage disease tendinopathies.

Moreover, the effectiveness demonstrated by the WB-EMS methods on participants with a high level of fitness appears to be of a practical relevance. In this case, the use of WB-EMS might be a valid alternative or a combination to adopt with more traditional means of training, where the managing of time could be of a certain interest for those professionals involved in a particular period of the season.
Several practical applications from this study have relevance to the strength and conditioning coach. First, these findings demonstrate the highly intense nature of the effects induced by the three different treatments, indicated by the very large effect sizes observed after the training period on the strength and muscle power of all the participants, for each treatment (Cohen's $d > 1$). Second, we can point out how significant effects can be achieved both by WB-EMS based on 50 and 85 Hz frequencies.

Conclusions

This study suggests that whole-body electrostimulations can be considered as a valid and faster alternative to a traditional overload-based resistance-training program for the development of dynamic strength. Comparing the two different WB-EMS approaches and circuit training, data showed a substantial parity of these methods of training.

Author Contributions

Conceptualization, S.D.; methodology, S.D., G.B. and B.R.; formal analysis, S.D., B.R. and G.B.; investigation, G.B., F.P., A.S., C.C., P.R.G. and A.B..; data curation, B.R. and G.B.; writing—original draft preparation, B.R., G.B., C.R. and S.D..; writing—review and editing, B..R., G.B., C.R. and S.D.; supervision, S.D.

Acknowledgements

The authors hereby declare that the experiments comply with the current laws of Italy, in which they were performed.

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Tables

	Loading Parameters (as % 1-RM)
Load 1 (L1)	15
Load 2 (L2)	35
Load 3 (L3)	65
Load 4 (L4)	85
1-RM = one repetition maximum estimated through Brzycki's formula (1993).	

Table 1 Force-velocity curve, initial loading parameters.

Parameters	WB-EMS1	WB-EMS2
Training Session Duration	20 min	20 min
Pulse duration	4 s	4 s
Pause between pulses	6 s	4 s
Duty cycle (per minute)	24"/36" (pulse to rest)	32"/28" (pulse to rest)
Pulse frequency	50 Hz	85 Hz
Pulse width	350 ms	350 ms
Pulse ramp	0.5 s	0.1 s
Perceived pulse intensity	Borg Scale CR-20 ranging from 14 to 16 ("somewhat hard" to "hard")	Borg Scale CR-20 ranging from 14 to 16 ("somewhat hard" to "hard")

Table 2 Electrical and methodological parameters of the whole body electrostimulation protocols adopted in this study.

Squatting Test (Force)	ICC (average measures)	CI (95 %)	p
L1 (pre-post)	0.943	−0.037–0.989	< 0.001
L2 (pre-post)	0.985	0.255–0.997	< 0.001
L3 (pre-post)	0.980	0.369–0.996	< 0.001
L4 (pre-post)	0.989	0.698–0.997	< 0.001
Squatting Test (Power)			
L1 (pre-post)	0.912	−0.048–0.983	< 0.001
L2 (pre-post)	0.958	0.152–0.991	< 0.001
L3 (pre-post)	0.954	−0.023–0.991	< 0.001
L4 (pre-post)	0.971	0.131–0.994	< 0.001

ICC = Intraclass correlation coefficient; **CI** = confidence interval. **L1** = loading 15 % 1-RM; **L2** = loading 35 % 1-RM; **L3** = loading 65 % 1-RM; **L4** = loading 85 % 1-RM; (pre-post) = pre treatment – post treatment).

Table 3 Intraclass correlation coefficients in squatting tests (Force and Power).

Barbell bench press Test (Force)	ICC (average measures)	CI (95 %)	p
L1 (pre-post)	0.992	0.626–0.998	< 0.001
L2 (pre-post)	0.983	0.472–0.996	< 0.001
L3 (pre-post)	0.993	0.522–0.999	< 0.001
L4 (pre-post)	0.988	0.358–0.998	< 0.001
Barbell bench press Test (Power)			
L1 (pre-post)	0.980	0.344–0.996	< 0.001
L2 (pre-post)	0.963	0.072–0.992	< 0.001
L3 (pre-post)	0.983	0.316–0.996	< 0.001
L4 (pre-post)	0.976	0.288–0.995	< 0.001

ICC = Intraclass correlation coefficient; **CI** = confidence interval. **L1** = loading 15 % 1-RM; **L2** = loading 35 % 1-RM; **L3** = loading 65 % 1-RM; **L4** = loading 85 % 1-RM; (pre-post) = pre treatment – post treatment).

Table 4 Intraclass correlation coefficients in barbell bench press tests (Force and Power).

Loading	WB-EMS 1					WB-EMS 2					CT-MDS				
	Pre Tr (N)	Post Tr (N)	Δ (%)	CI 95 %	PS t-Test	Pre Tr (N)	Post Tr (N)	Δ (%)	CI 95 %	PS t-Test	Pre Tr (N)	Post Tr (N)	Δ (%)	CI 95 %	PS t-Test
L1	262.48 (14.97)	279.22 (16.66)	+6.00	LB = −22.38 UB = −11.10	t = −7.63 df = 5 P = **0.001** d = −3.12	243.11 (51.00)	261.59 (54.66)	+7.07	LB = −23.08 UB = −13.89	t = −9.51 df = 7 P < **0.001** d = −3.36	261.40 (38.00)	282.20 (41.80)	+7.37	LB = −26.02 UB = −15.58	t = −9.42 df = 7 P < **0.001** d = −3.33
L2	478.80 (46.98)	507.91 (43.50)	+5.73	LB = −22.38 UB = −11.10	t = −8.28 df = 5 P < **0.001** d = −3.38	367.17 (95.94)	383.26 (94.01)	+4.20	LB = −22.36 UB = −9.82	t = −6.07 df = 7 P = **0.001** d = −2.14	440.64 (121.20)	468.79 (130.17)	+6.00	LB = −38.76 UB = −17.54	t = −6.27 df = 7 P < **0.001** d = −2.21
L3	676.77 (98.79)	694.49 (101.64)	+2.55	LB = −22.38 UB = −11.10	t = −4.23 df = 5 P = **0.008** d = −1.73	476.22 (100.67)	529.05 (109.33)	+9.98	LB = −62.74 UB = −42.91	t = −12.60 df = 7 P < **0.001** d = −4.45	587.35 (202.37)	633.01 (225.16)	+7.21	LB = −70.07 UB = −21.23	t = −4.42 df = 7 P = **0.003** d = −1.56
L4	818.11 (128.0)	848.04 (139.45)	+3.53	LB = −22.38 UB = −11.10	t = −5.94 df = 5 P = **0.002** d = −2.43	603.77 (138.27)	661.72 (143.56)	+8.76	LB = −70.24 UB = −45.65	t = −11.15 df = 7 P < **0.001** d = −3.94	732.88 (260.20)	749.60 (272.87)	+4.64	LB = −33.82 UB = 0.40	t = −5.94 df = 7 P = **0.054** d = −0.81

L1 = loading 15% 1-RM; L2 = loading 35% 1-RM; L3 = loading 65% 1-RM; L4 = loading 85% 1-RM. Pre Tr = Pre Treatment; Post Tr = Post Treatment; M (SD); N = Newton. Δ (%) = Percentage of variations between pre and post scores (means) CI95% = Confidence Interval for the differences; LB = lower bound; UB = upper bound. PS t-Test = Paired Samples t-Test; t = t values; df = degree of freedom; P = P values (P values in bold are significant); d = Cohen's d values. (Effect Size; ES). Absolute ES of 0.20, 0.50, 0.80, >1 represent small, medium, large and huge effects, respectively.

Table 5 Squatting. Force-velocity curve loading parameters: Force values recorded pre and post the different experimental and control treatments (WB-EMS 1, WB-EMS 2 and CT-DS) in the different groups. Within-group differences (paired sample t Test). Force values are expressed in Newton (N).

Loading	WB-EMS 1					WB-EMS 2					CT-MDS				
	Pre Tr (W)	Post Tr (W)	Δ (%)	CI 95%	PS t-Test	Pre Tr (W)	Post Tr (W)	Δ (%)	CI 95%	PS t-Test	Pre Tr (W)	Post Tr (W)	Δ (%)	CI 95%	PS t-Test
L1	180.59 (30.20)	214.97 (34.75)	+15.99	LB= −40.75 UB= −28.01	t= −13.87 df=5 P< **0.001** d= −5.66	161.17 (40.48)	190.92 (49.29)	+15.58	LB= −38.30 UB= −21.21	t= −8.23 df=7 P< **0.001** d= −2.91	185.55 (68.29)	216.94 (75.91)	+14.47	LB= −39.53 UB= −23.25	t= −9.12 df=7 P< **0.001** d= −3.22
L2	292.57 (61.85)	355.55 (76.62)	+17.71	LB= −84.33 UB= −41.61	t= −7.58 df=5 P= **0.001** d= −3.09	228.16 (91.44)	248.90 (33.76)	+8.33	LB= −20.74 UB= −8.75	t= −6.71 df=7 P< **0.001** d= −2.37	273.92 (133.84)	313.65 (149.45)	+12.67	LB= −56.68 UB= −22.77	t= −6.27 df=7 P= **0.001** d= −1.95
L3	349.19 (104.2)	403.23 (113.37)	+13.40	LB= −67.02 UB= −41.06	t= −4.23 df=5 P< **0.001** d= −4.37	256.95 (95.56)	307.04 (110.72)	+16.31	LB= −63.74 UB= −36.46	t= −8,68 df=7 P< **0.001** d= −3.07	313.27 (157.18)	372.15 (190.02)	+15.82	LB= −87.41 UB= −30.34	t= −4.88 df=7 P= **0.002** d= −1.72
L4	362.69 (120.4)	415.64 (139.01)	+12.74	LB= −73.48 UB= −32.41	t= −6.63 df=5 P= **0.001** d= −2.70	259.36 (111.98)	311.27 (124.63)	+16.68	LB= −65.36 UB= −38.45	t= −9.124 df=7 P< **0.001** d= −3.22	326.61 (166.02)	357.42 (187.35)	+8.62	LB= − −52.25 UB= −9.37	t= −3.40 df=7 P= **0.01** d= −1.20

L1 =loading 15% 1-RM; L2 =loading 35% 1-RM; L3 =loading 65% 1-RM; L4= loading 85% 1-RM - Pre Tr= Pre Treatment; Post Tr= Post Treatment; M (SD); W = Watt. Δ (%)= Percentage of variations between pre and post scores (means) - CI95% =Confidence Interval for the differences; LB = lower bound; UB =upper bound; PS t-Test=Paired Samples t-Test; t= t values; df =degree of freedom; P= P values (P values in bold are significant); d = Cohen's d values. (Effect Size; ES). Absolute ES of 0.20, 0.50, 0.80, > 1 represent small, medium, large and huge effects, respectively.

Table 6 Squatting. Force-velocity curve loading parameters: Power values recorded pre and post the different experimental and control treatments (WB-EMS 1, WB-EMS 2 and CT-MDS) in the different groups. Within-group differences (paired sample t Test). Pre and post treatment Power values are expressed in Watt (W).

	Within			Between			Interaction		
	F_{df}	P	$\eta^2_{part.}$	F_{df}	P	$\eta^2_{part.}$	F_{df}	P	$\eta^2_{part.}$
L1	$227.620_{1,19}$	**<0.001**	0.923	$0.552_{2,19}$	0.585	0.055	$0.878_{2,19}$	0.432	0.085
L2	$129.698_{1,19}$	**<0.001**	0.872	$2.695_{2,19}$	0.093	0.221	$3.992_{2,19}$	**0.036**	0.296
L3	$82.264_{1,19}$	**<0.001**	0.812	$2.535_{2,19}$	0.106	0.211	$5.767_{2,19}$	**0.011**	0.378
L4	$95.810_{1,19}$	**<0.001**	0.835	$1.837_{2,19}$	0.186	0.162	$12.844_{2,19}$	**<0.001**	0.575

L1 = loading 15 % 1-RM; L2 = loading 35 % 1-RM; L3 = loading 65 % 1-RM; L4 = loading 85 % 1-RM. Two way ANOVA [2 x 3]: F = F values and degrees of freedom; P = P values (P values in bold are significant); η^2_{part} = Partial ETA squared as Effect Size; (ES). Absolute partial ETA squared values < 0.01; $0.01 < \eta^2_{part} < 0.06$; $0.06; < \eta^2_{part} < 0.14$; > 0.14 represent trivial, small, moderate and large effects, respectively.

Table 7 Two way ANOVA [2 (pre-post) x 3 (control and experimental conditions)] - Squatting. Force-velocity loading parameters: within, between group differences and interactions found in the force values (WB-EMS1 vs. WB-EMS2 vs. CT-DS) recorded pre and post the different experimental and control treatments.

	Within			Between			Interaction		
	F_{df}	P	$\eta^2_{part.}$	F_{df}	P	$\eta^2_{part.}$	F_{df}	P	$\eta^2_{part.}$
L1	$263.541_{1,19}$	**<0.001**	0.933	$0.496_{2,19}$	0.617	0.050	$0.446_{2,19}$	0.647	0.045
L2	$126.684_{1,19}$	**<0.001**	0.870	$1.134_{2,19}$	0.343	0.107	$10.598_{2,19}$	**0.001**	0.527
L3	$112.377_{1,19}$	**<0.001**	0.855	$0.898_{2,19}$	0.424	0.086	$0.764_{2,19}$	**0.028**	0.545
L4	$100.737_{1,19}$	**<0.001**	0.841	$0.896_{2,19}$	0.425	0.086	$2.697_{2,19}$	0.093	0.221

L1 = loading 15 % 1-RM; L2 = loading 35 % 1-RM; L3 = loading 65 % 1-RM; L4 = loading 85 % 1-RM. Two way ANOVA [2 x 3]: F = F values and degrees of freedom; P = P values (P values in bold are significant); η^2_{part} = Partial ETA squared as Effect Size; (ES). Absolute partial ETA squared values < 0.01; $0.01 < \eta^2_{part} < 0.06$; $0.06; < \eta^2_{part} < 0.14$; > 0.14 represent trivial, small, moderate and large effects, respectively.

Table 8 Two way ANOVA [2 (pre-post) x 3 (control and experimental conditions)] - Squatting. Force-velocity loading parameters: within, between group differences and interactions found in the Power values (WB-EMS1 vs. WB-EMS2 vs. CT-MDS) recorded pre and post the different experimental and control treatments.

Loading	WB-EMS 1					WB-EMS 2					CT-MDS				
	Pre Tr (N)	Post Tr (N)	Δ (%)	CI 95 %	PS t-Test	Pre Tr (N)	Post Tr (N)	Δ (%)	CI 95 %	PS t-Test	Pre Tr (N)	Post Tr (N)	Δ (%)	CI 95 %	PS t-Test
L1	206.01 (75.40)	222.97 (82.07)	+7.57	LB = −25.66 UB = −8.09	t = −4.93 df = 5 P = **0.004** d = −2.01	132.54 (74.28)	146.31 (81.97)	+9.41	LB = −20.34 UB = −7.18	t = −4.94 df = 7 P < **0.002** d = −1.74	173.75 (109.47)	187.30 (117.94)	+7,23	LB = −21.42 UB = −5.67	t = −4.06 df = 7 P < **0.005** d = −1.43
L2	260.98 (99.45)	306.99 (111.89)	+14.99	LB = −60.79 UB = −31.22	t = −7.99 df = 5 P < **0.001** d = −3.26	185.98 (100.46)	204.77 (105.24)	+9.17	LB = −23.80 UB = −13.76	t = −8.85 df = 7 P < **0.001** d = −3.13	270.35 (116.65)	286.51 (120.25)	+5.64	LB = −21.44 UB = −10.88	t = −7.24 df = 7 P < **0.001** d = −2.56
L3	375.13 (114.65)	393.35 (114.99)	+4.63	LB = −29.69 UB = −6.75	t = −4.08 df = 5 P = **0.010** d = −1.66	262.10 (109.72)	285.66 (118.14)	+8.25	LB = −31.96 UB = −15.19	t = −6.65 df = 7 P < **0.001** d = −2.87	359.59 (136.88)	375.97 (142.76)	+4.36	LB = −22.64 UB = −10.12	t = −6.18 df = 7 P < **0.001** d = −2.19
L4	461.61 (97.89)	500.47 (104.72)	+7.76	LB = −51.04 UB = −26.67	t = −8.19 df = 5 P < **0.001** d = −3.34	345.43 (111.19)	375.35 (117.91)	+7.97	LB = −36.90 UB = −22.96	t = −10.15 df = 7 P < **0.001** d = −3.59	432.27 (165.58)	447.31 (171.36)	+3.36	LB = −20.89 UB = −9.18	t = −6.07 df = 7 P = **0.001** d = −2.14

L1 = loading 15 % 1-RM; **L2** = loading 35 % 1-RM; **L3** = loading 65 % 1-RM; **L4** = loading 85 % 1-RM. **Pre Tr** = Pre Treatment; **Post Tr** = Post Treatment; M (SD); N = Newton. **Δ (%)** = Percentage of variations between pre and post scores (means). **CI95 %** = Confidence Interval for the differences; LB = lower bound; UB = upper bound; **PS t-Test** = Paired Samples t-Test; **t** = t values; **df** = degree of freedom; **P** = P values (P values in bold are significant); **d** = Cohen's d values. (Effect Size; ES). Absolute ES of 0.20, 0.50, 0.80, > 1 represent small, medium, large and huge effects, respectively.

Table 9 Barbell bench press. Force-velocity curve loading parameters: Force values recorded pre and post the different experimental and control treatments (WB-EMS 1, WB-EMS 2 and CT-DS) in the different groups. Within-group differences (paired sample t Test). Force values are expressed in Newton (N).

Loading	WB-EMS 1					WB-EMS 2					CT-MDS				
	Pre Tr (W)	Post Tr (W)	Δ (%)	CI 95 %	PS t-Test	Pre Tr (W)	Post Tr (W)	Δ (%)	CI 95 %	PS t-Test	Pre Tr (W)	Post Tr (W)	Δ (%)	CI 95 %	PS t-Test
L1	164.34 (67.60)	187.92 (76.20)	+ 12.55	LB = −39.70 UB = −11.45	t = −4.99 df = 5 P = **0.004** d = −2.04	95.73 (54.17)	112.38 (63.60)	+ 14.82	LB = −24.78 UB = −8.51	t = −4.84 df = 7 P = **0.002** d = −1.71	127.02 (85.87)	146.11 (97.06)	+ 13.06	LB = −29.75 UB = −8.42	t = −4.23 df = 7 P = **0.004** d = −1.49
L2	168.19 (71.12)	210.18 (85.66)	+ 19.98	LB = −57.91 UB = −26.07	t = −6.78 df = 5 P = **0.001** d = −2.76	113.68 (63.40)	137.81 (74.30)	+ 17.51	LB = −33.59 UB = −14.66	t = −6.02 df = 7 P = **0.001** d = −2.13	168.44 (88.77)	191.89 (99.34)	+ 12.22	LB = −33.32 UB = −13.60	t = −5.62 df = 7 P = **0.001** d = −1.99
L3	198.64 (85.04)	214.27 (88.08)	+ 7.29	LB = −24.36 UB = −6.90	t = −4.60 df = 5 P = **0.006** d = −1.87	125.49 (66.60)	151.73 (78.31)	+ 17.30	LB = −36.50 UB = −15.98	t = −6.05 df = 7 P < **0.001** d = −2.13	180.41 (109.03)	202.67 (119.17)	+ 10.99	LB = −32.38 UB = −12.15	t = −5.21 df = 7 P = **0.001** d = −1.84
L4	192.89 (91.97)	221.56 (104.43)	+ 12.94	LB = −42.37 UB = −14.97	t = −5.378 df = 5 P = **0.003** d = −2.19	100.96 (63.86)	129.65 (78.82)	+ 22.13	LB = −41.45 UB = −15.94	t = −5.32 df = 7 P = **0.001** d = −1.88	154.15 (102.33)	176.06 (116.63)	+ 12.45	LB = − −36.11 UB = −7.72	t = −3.65 df = 7 P = **0.008** d = −1.29

L1 = loading 15 % 1-RM; **L2** = loading 35 % 1-RM; **L3** = loading 65 % 1-RM; **L4** = loading 85 % 1-RM; **Pre Tr** = Pre Treatment; **Post Tr** = Post Treatment; M (SD); W = Watt. **Δ (%)** = Percentage of variations between pre and post scores (means); **CI95 %** = Confidence Interval for the differences; LB = lower bound; UB = upper bound. **PS t-Test** = Paired Samples t-Test; **t** = t values; **df** = degree of freedom; **P** = P values (P values in bold are significant); **d** = Cohen's d values. (Effect Size: ES). Absolute ES of 0.20, 0.50, 0.80, > 1 represent small, medium, large and huge effects, respectively.

Table 10 Barbell bench press. Force-velocity curve loading parameters: Power values recorded pre and post the different experimental and control treatments (WB-EMS 1, WB-EMS 2 and CT-DS) in the different groups. Within-group differences (paired sample t Test). Pre and post treatment Power values are expressed in Watt (W).

	Within			Between			Interaction		
	F_{df}	P	$\eta^2_{part.}$	F_{df}	P	$\eta^2_{part.}$	F_{df}	P	$\eta^2_{part.}$
L1	$63.354_{1,19}$	**<0.001**	0.769	$1.143_{2,19}$	0.340	0.107	$0.307_{2,19}$	0.739	0.031
L2	$196.145_{1,19}$	**<0.001**	0.912	$1.553_{2,19}$	0.237	0.140	$22.319_{2,19}$	**<0.001**	0.701
L3	$91.106_{1,19}$	**<0.001**	0.827	$1.710_{2,19}$	0.208	0.153	$1.239_{2,19}$	0.312	0.115
L4	$212.991_{1,19}$	**<0.001**	0.918	$1.496_{2,19}$	0.249	0.136	$12.994_{2,19}$	**<0.001**	0.578

L1 = loading 15 % 1-RM; L2 = loading 35 % 1-RM; L3 = loading 65 % 1-RM; L4 = loading 85 % 1-RM. Two way ANOVA [2 x 3]: F = F values and degrees of freedom; P = P values (P values in bold are significant); η^2_{part} = Partial ETA squared as Effect Size; (ES). Absolute partial ETA squared values < 0.01; 0.01 < η^2_{part} < 0.06; 0.06; < η^2_{part} < 0.14; > 0.14 represent trivial, small, moderate and large effects, respectively.

Table 11 Two way ANOVA [2 (pre-post) x 3 (control and experimental conditions)] - Barbell bench press. Force-velocity loading parameters: within, between- group differences and interactions found in the force values (WB-EMS1 vs. WB-EMS2 vs. CT-MDS) recorded pre and post the different experimental and control treatments.

	Within			Between		Interaction			
	F_{df}	P	$\eta^2_{part.}$	F_{df}	P	$\eta^2_{part.}$	F_{df}	P	$\eta^2_{part.}$
L1	$64.975_{1,19}$	**<0.001**	0.774	$1.560_{2,19}$	0.236	0.141	$0.638_{2,19}$	0.539	0.063
L2	$121.090_{1,19}$	**<0.001**	0.864	$1.328_{2,19}$	0.289	0.123	$4.548_{2,19}$	**0.024**	0.324
L3	$77.337_{1,19}$	**<0.001**	0.803	$1.074_{2,19}$	0.361	0.102	$1.520_{2,19}$	0.244	0.138
L4	$63.706_{1,19}$	**<0.001**	0.770	$1.674_{2,19}$	0.214	0.150	$0.492_{2,19}$	0.619	0.049

L1 = loading 15 % 1-RM; L2 = loading 35 % 1-RM; L3 = loading 65 % 1-RM; L4 = loading 85 % 1-RM. Two way ANOVA [2 x 3]: F = F values and degrees of freedom; P = P values (P values in bold are significant); η^2_{part} = Partial ETA squared as Effect Size; (ES). Absolute partial ETA squared values < 0.01; 0.01 < η^2_{part} < 0.06; 0.06; < η^2_{part} < 0.14; > 0.14 represent trivial, small, moderate and large effects, respectively.

Table 12 Two way ANOVA [2 (pre-post) x 3 (control and experimental conditions)] - Barbell bench press. Force-velocity loading parameters: within, between-group differences and interactions found in the Power values (WB-EMS1 vs. WB-EMS2 vs. CT-MDS) recorded pre and post the different experimental and control treatments.

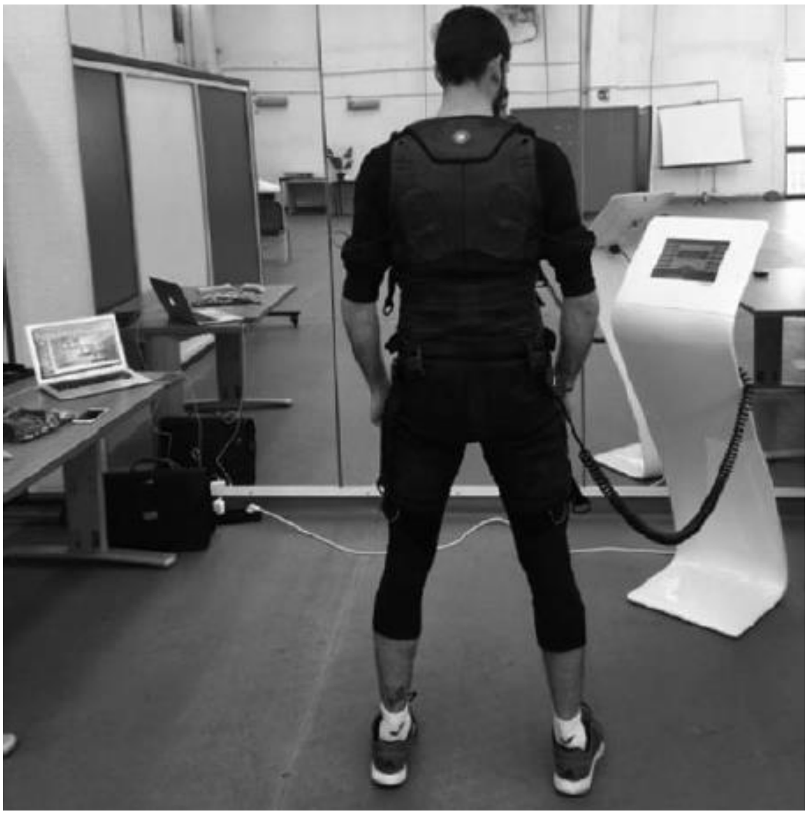

Fig. 1 The gym suit with multiple electrodes used in this study

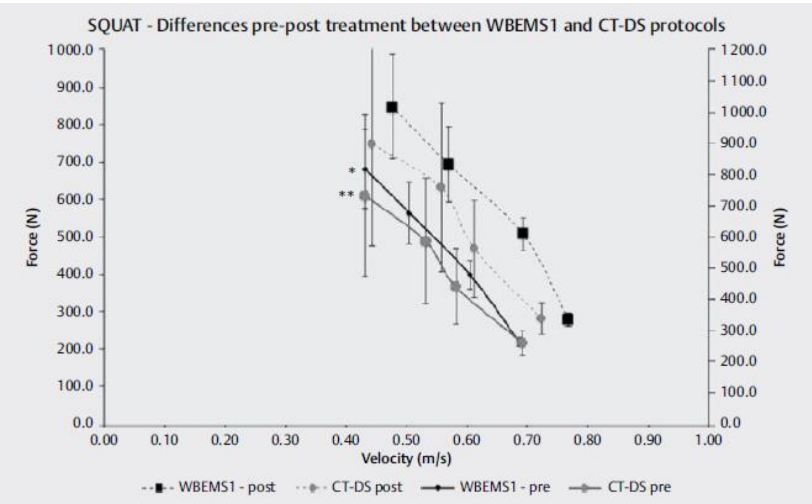

Fig. 2 Squatting test. Force-velocity curves drawn before and after treatment (mean values ± SD; Y axis SD = Force): WB-EMS1 protocol vs. CT-DS protocol (control) – Note the increased values posttreatment ($p < 0.05$, Cohen's $d > 1$).

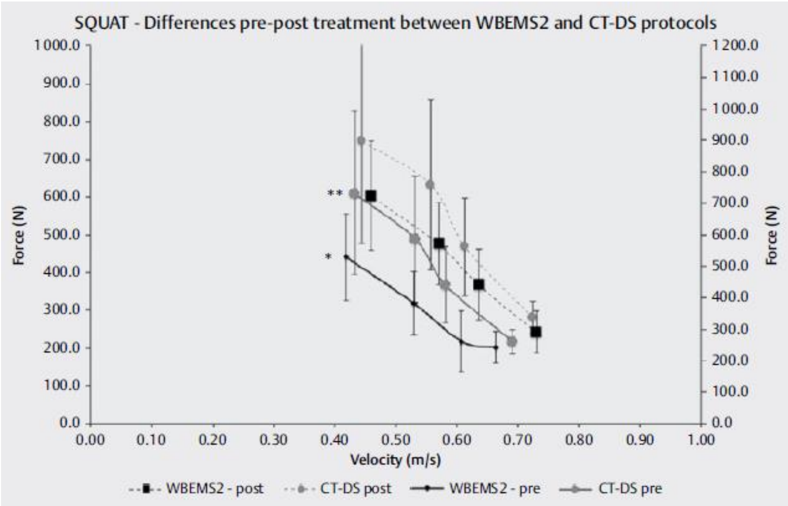

Fig. 3 Squatting test. Force-velocity curves drawn before and after treatment (mean values ± SD; Y axis SD = Force): WB-EM2 protocol vs. CT-DS protocol (control) – Note the increased values posttreatment ($p < 0.05$, Cohen's d > 1).

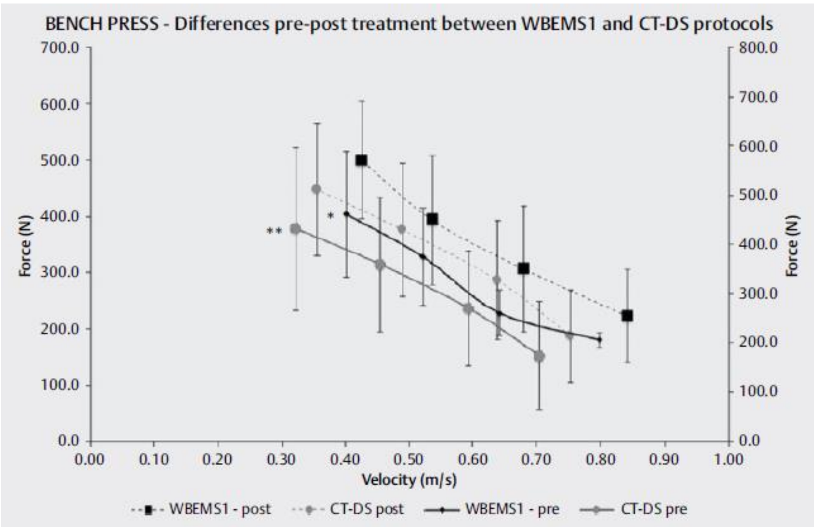

Fig. 4 Bench press test. Force-velocity curves drawn before and after treatment (mean values ± SD; Y axis SD = Force): WB-EMS1 protocol vs. CT-DS protocol (control) – Note the increased values post-treatment ($p < 0.05$, Cohen's d > 1).

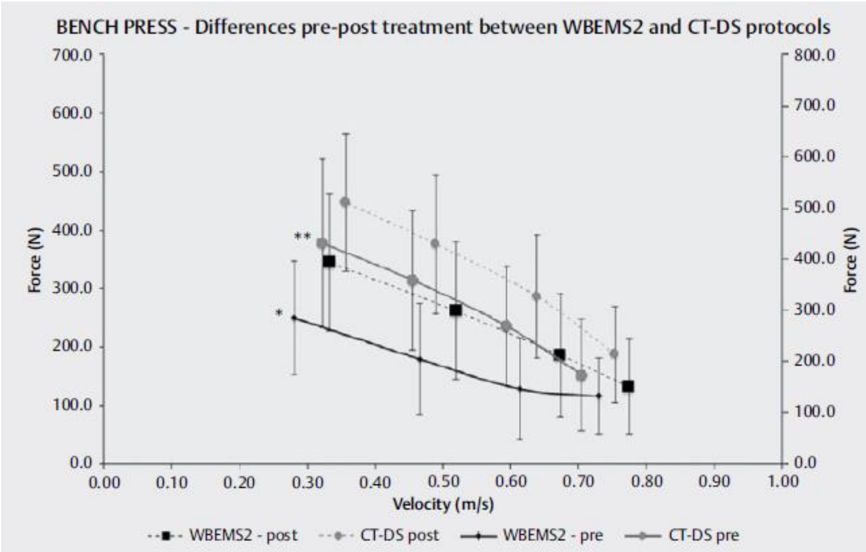

Fig. 5 Bench press test. Force-velocity curves drawn before and after treatment (mean values ± SD; Y axis SD = Force): WB-EM2 protocol vs. CT-DS protocol (control) – Note the increased values post-treatment ($p < 0.05$, Cohen's $d > 1$).