

EFFECTS OF SIMULTANEOUSLY COMBINED WHOLE-BODY ELECTROSTIMULATION AND PLYOMETRIC TRAINING ON VERTICAL JUMP PERFORMANCE, 20 M SPRINT-TIME AND HANDGRIP STRENGTH

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Abstract

Introduction. The aim of the present study was to investigate the effects of a 6-week low intensity plyometric training (PT) + whole-body electrostimulation (WBES) combined program, compared with traditional PT, on vertical jump performance, 20 m sprint-time and handgrip strength. **Material and methods.** 10 male and 10 female Physical Education students were randomly allocated to a control (CON) or an experimental (EXP) group. Both groups performed a 6-week low intensity PT 3 days per week, and during the third day, PT was simultaneously combined with WBES in the EXP group. Countermovement jump (CMJ) height, CMJ peak power, 20 m sprint-time and handgrip strength were measured before (pre-test) and after (post-test) the training period. Repeated measures ANOVA was performed to identify differences after the training program. Effect sizes (ES) were assessed using Hedge's g. **Results.** No significant differences between groups were observed at post-test. CMJ height and CMJ peak power significantly increased in both groups, with greater ES in the EXP group ($p < 0.001$, $g = 0.68$; $p < 0.001$, $g = 0.70$, respectively). 20 m sprint-time significantly improved in both groups, with greater ES in the CON group ($p < 0.001$, $g = -1.68$). Handgrip strength also increased in both groups, but ES were minimal. **Conclusions.** Both training methods demonstrated to be a good strategy to improve CMJ performance and 20 m sprint-time. The most effective training method for improving CMJ performance was PT + WBES combined program, and traditional PT obtained better results in 20 m sprint-time.

Key words: countermovement jump, sprint, plyometrics, electrostimulation, muscular strength

Introduction

Plyometric training (PT) is a specific training method whose main objective is to enhance the stretch-shortening cycle, resulting in an increased ability of the muscles to develop maximum strength and explosive power, which are necessary for the success of many athletic performances [1, 2]. The development of higher concentric strength after a period of plyometric training is due to a better use of the stretch-shortening cycle and to a more powerful myotatic reflex [2, 3]. As a result, this method leads to an increase in jumping ability and an improvement in intramuscular coordination [4].

PT is mainly carried out with repetitive jumps, hops in place and depth jumps [3]. PT enhances the use of the stretch-shortening cycle as an effect of the reduction in the time required for the transition from the eccentric to the concentric phase of the jump [5]. Regular assessment of jumping ability during a competitive season is especially useful in certain sports to introduce individual adjustments in training sessions [6]. After a PT program, a higher vertical jump height and higher peak force of the lower limbs are usually obtained [4, 7, 8]. In order to be effective, PT has to be administered 2-3 times a week, and the results are better if it is combined with other specific types of training [5].

Electrostimulation is also known to be an effective training method to improve athletic performance, in healthy subjects and highly trained athletes [9, 10]. It helps in achieving greater strength and power adaptations by a synchronous recruitment

of muscle fibers and an increased firing rate [11]. Electrostimulation consists of electrical currents applied in muscles or peripheral nerves in order to provoke involuntary muscle contractions [12]. Its main advantage for athletes is an increase in the maximum strength and power during voluntary contractions [13, 14].

However, electrostimulation has also important disadvantages, such as Golgi tendon organ and myotatic reflex inhibition, which can lead to an increased injury risk if its use is not adequate [15]. Moreover, the functional transfer of these gains into sports movements is more relevant [16] and, in order to achieve this functional transfer and to develop higher force and power, electrostimulation has to be combined or superimposed with sport-specific exercises [17, 18]. Its simultaneous combination with PT has proven to be more effective for the improvement in vertical jump ability [19] and 30 m sprint-time [20, 21] than PT alone.

Compared to local electrostimulation, whole-body electrostimulation (WBES) stimulates several muscle groups simultaneously during dynamic movements. Micke et al. [16] indicate that the combination of dynamic exercises superimposed with submaximal WBES is effective in improving leg strength and power. In non-athletic adults, WBES improves muscle mass and function, and reduces fat mass and low back pain [22]. There is evidence of some risk factors and adverse effects of a WBES program due to an inappropriately high current intensity, an inadequate energy and liquid supply prior and after the session, etc. However, when properly applied and supervised, it appears to be a safe technology [22].

Handgrip strength is the isometric force of the hand evaluated with a hand dynamometer. It is widely used as a predictive measure of several health markers [23, 24]. Handgrip strength has been used as an indicator of basic health and fitness [25, 26] and it has also been investigated as a predictor of performance [27, 28]. In addition, the relationship between handgrip strength and the muscular strength of the lower limbs has been recently investigated. Some authors observed a relationship between handgrip strength and vertical jump height [29, 30], while others did not [31, 32], and Matsudo et al. [29] found a moderate negative correlation between handgrip strength and the time taken to run 50 m.

Due to the scarcity of studies analyzing the effects of simultaneously combined PT and WBES on leg strength and power, together with the contradictory results observed for the relationship between handgrip strength and the muscular strength of the lower limbs, the aim of the present study was to investigate the effects of a 6-week low intensity PT + WBES combined program, compared with traditional PT, on vertical jump performance, 20 m sprint-time and handgrip strength in a group of male and female students of Physical Education, aged 19-25 years. It was hypothesised that low intensity PT + WBES combined program would result in a greater improvement in vertical jump performance and 20 m sprint-time.

Material and Methods

Participants

10 male and 10 female students of Physical Education aged 19-25 years volunteered to participate in this study. All participants had a minimum experience of 3 years in different sports modalities (soccer, swimming, padel and running) and trained for more than 3 hours per week. The participants were randomly



Figure 1. Miha Bodytec II ES unit and electrode vest

allocated to two different groups with 5 women and 5 men each: control (CON) group (22.50 ± 1.43 years, 171.30 ± 7.57 cm, 65.50 ± 11.22 kg), and experimental (EXP) group (22.30 ± 1.42 years, 169.60 ± 8.73 cm, 66.40 ± 10.63 kg). The groups were homogeneous in terms of age, body mass, and body height. None of the participants had experienced serious injuries at least 12 months before the testing sessions. All the participants gave written informed consent according to the Declaration of Helsinki.

Training program

The CON and EXP groups performed a low intensity PT 3 days per week, and during the third day, PT was simultaneously combined with WBES in the EXP group. In order to prepare the participants for the following six weeks of PT and to prevent injuries, there were 2 familiarization sessions with a low number of low intensity jumps. The training sessions lasted about 45 minutes and consisted of a standard 10-minute warm-up routine (including low speed running, hopping in place, dynamic stretching exercises and one set of five submaximal jumps), a 30-minute main session and a 5-minute cool down. The PT program consisted of eight different exercises adapted from those used in the literature with low/moderate intensity [33, 34]. There was a progressive increase in the intensity of the exercises, and the number of jumps increased from 100 jumps in the first week to 140 jumps in the last week. Rest intervals were 1 minute between sets and 2 minutes between exercises. The complete training program is shown in table 1.

A Miha Bodytec II ES unit (Miha Bodytec, Augsburg, Germany) was used for the WBES application (Fig. 1). It consisted of an electrode vest with fixed surface electrodes for stimulation of the upper body, and some non-fixed electrodes for the stimulation of the muscles of glutes, the thighs and the calves. The sizes of the electrode vest and the non-fixed electrodes were selected according to the body size of the participant. The electrodes were placed by two well-trained professionals. Prior to the study, the subjects participated in one familiarization session with the electrostimulation unit. The electrostimulation parameters were: 120 Hz stimulation frequency (explosive strength), 350 ms pulse width, and contraction-relaxation time of 5 to 10 seconds. Each session lasted 13 minutes, including 3-minute warm-up with a frequency of 7 Hz. The intensity level was set individually at the maximum tolerated [35]. The combined training consisted of series of jumps that the athletes performed during the 5 s with electrical current, followed by a 10 s rest-time when the current was not applied. The following

Table 1. 6-week low intensity plyometric training program

Exercise volume	Sets and repetitions					
Type of exercise	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6
Frontal hops	2 x 10	2 x 10				
Lateral hops	2 x 10	2 x 10	2 x 10	2 x 10		
Hurdle jumps (25 cm)	2 x 10	2 x 10	2 x 10	2 x 10	2 x 10	2 x 10
CMJ	2 x 10	2 x 10	2 x 10	2 x 10	2 x 15	2 x 15
Squat jumps			2 x 10	2 x 10	2 x 10	2 x 10
Box jumps (25 cm)	2 x 10	2 x 10	2 x 10	2 x 10	2 x 10	3 x 10
Lunge jumps			2 x 10	2 x 10	2 x 15	2 x 15
Drop jumps (25 cm)					2 x 10	2 x 10
Total number of jumps	100	100	120	120	140	140

exercises were used: frontal hops, lateral hops, hurdle jumps, tuck jumps, butt kick jumps and repeated CMJ. The total number of jumps of each session was different for each participant.

Testing procedures

All participants were tested one week before (pre-test) and one week after (post-test) the 6-week training. One preparatory session was undertaken some days before the data collection. During the data collection session, participants performed the tests in the following order: CMJ, 20 m sprints and handgrip strength tests.

Jump tests

Following a standard warm-up routine of 15 minutes, all participants performed 3 maximal CMJ without arm swing on a Chronojump contact mat (Chronojump Boscossystem, Barcelona, Spain), with a minute rest between them. Participants were allowed to jump with their preferred self-selected countermovement depth and they were instructed to jump “as high as possible” keeping their hands on their hips. The highest jump of the three trials was used for subsequent analysis. In our previous investigations, vertical jump height measured with the Chronojump contact mat showed excellent reliability with an intraclass correlation coefficient (ICC) of 0.864 and a within-subject coefficient of variation (CV) of 3.82%. Peak power during the propulsion phase of CMJ was calculated with Sayers power equation [36]: Peak power (Watts) = $60.7 * \text{Jump height (cm)} + 45.3 * \text{body mass (kg)} - 2055$. Peak power normalized to body mass was used for analysis.

Sprint tests

Prior to the sprint test, participants undertook a standard warm-up routine of 15 minutes, which included sprint drills and progressive sprints. Then, participants performed 3 maximum effort sprints of 20 m with 3-minute rest periods. Sprint time was measured using the Witty Timing System (Microgate SRL, Italy). The best of 3 trials was used for analysis. In our previous investigations, test-retest reliability for 20 m sprint-time with the Witty Timing System gave an ICC of 0.807 and a CV of 4.19%.

Handgrip strength

The grip strength of both right and left hands was measured using a Jamar handgrip dynamometer (Asimow Engineering

Co., USA). The handgrip strength was recorded in kilograms. Participants performed the test three times for each hand, with a minute rest between them and alternating right and left hands. They were instructed to squeeze the handgrip with maximum force with an outstretched arm, at a standing position. The sum of the best results for the right and left hand was used for analysis. In previous investigations, we measured test-retest reliability for maximal isometric handgrip strength with a Jamar dynamometer and obtained an ICC of 0.791 and a CV of 4.45%.

Statistical analysis

Statistical analysis was conducted using SPSS software for Windows, v. 22.0 (SPSS Inc., USA). Means and standard deviations of all variables were calculated. Shapiro-Wilk test was applied for testing normality of data. As this condition was always fulfilled, independent samples T-Student tests were carried out to determine initial significant differences between groups. After following the training program, a two-way repeated measures ANOVA was performed. In case of a significant group x time interaction, Bonferroni post hoc tests were carried out for pairwise comparison. In addition, effect sizes (ES) were assessed using Hedge's *g* with the correction for small sample sizes and they were interpreted according to the following criteria: minimal effect (< 0.20), small effect ($0.20-0.50$), moderate effect ($0.50 - 0.80$) or large effect (> 0.80) [37]. The statistical level of significance was set as $p < 0.05$ for all analyses.

Results

No significant differences in any of the variables measured were observed between groups at pre-test, which means that the random assignment of participants was successful, and both groups were homogeneous at baseline. Table 2 presents means and standard deviations of all the variables measured at pre-test and post-test in both groups. Significant differences between pre-test and post-test scores within groups, percentage changes, and ES are also shown in table 2.

CMJ height and CMJ peak power significantly increased in both groups, with small ES in the CON group ($p = 0.007$, $g = 0.45$; $p < 0.006$, $g = 0.49$, respectively) and moderate ES in the EXP group ($p < 0.001$, $g = 0.68$; $p < 0.001$, $g = 0.70$, respectively). 20 m sprint-time significantly improved in both groups, with a large ES in the CON group ($p < 0.001$, $g = -1.68$) and a moderate ES in the EXP group ($p = 0.003$, $g = -0.75$). Final-

Table 2. Descriptive statistics of the study variables, changes pretest-posttest, significant differences, and effect sizes in both groups

Variables	Groups	Pretest Mean \pm sd	Posttest Mean \pm sd	p-value	Changes (%) Mean \pm sd	Hedges' <i>g</i> (effect size)
CMJ height (cm)	CON group	24.37 \pm 4.16	26.50 \pm 4.91	0.007	9.07 \pm 8.54	0.45
	EXP group	23.72 \pm 4.08	27.00 \pm 5.07	< 0.001	13.68 \pm 8.54	0.68
CMJ Peak Power (W * kg ⁻¹)	CON group	37.30 \pm 3.23	39.19 \pm 4.16	0.006	5.12 \pm 7.13	0.49
	EXP group	36.03 \pm 4.72	39.48 \pm 4.72	< 0.001	9.75 \pm 3.20	0.70
20 m sprint-time (s)	CON group	3.33 \pm 0.17	3.04 \pm 0.16	< 0.001	-8.44 \pm 5.50	-1.68
	EXP group	3.31 \pm 0.22	3.15 \pm 0.19	0.003	-4.70 \pm 2.57	-0.75
Handgrip strength (kg)	CON group	76.17 \pm 16.03	79.16 \pm 18.23	0.042	3.57 \pm 4.16	0.17
	EXP group	71.03 \pm 19.70	74.14 \pm 18.10	0.035	5.52 \pm 8.76	0.16

Sd – standard deviation; CMJ – countermovement jump; CON – control; EXP – experimental.

ly, handgrip strength also increased in both groups, but the ES were minimal ($p = 0.042$, $g = 0.17$; $p = 0.035$, $g = 0.16$, respectively). No significant differences between groups were found at post-test.

Discussion

The purpose of this study was to investigate the effects of a 6-week low intensity PT + WBES combined program, compared with traditional PT, on vertical jump performance, 20 m sprint-time and handgrip strength, in a group of Physical Education students. We hypothesized that low intensity PT + WBES combined program would result in greater improvements in vertical jump performance and 20 m sprint-time. However, no significant differences in any of the variables measured were found between groups at post-test.

After 6 weeks of low intensity traditional PT, CMJ height and CMJ peak power significantly increased in the CON group. The increase percentage rate was 9.07% and 5.12%, respectively, and both ES were small. These results were expected because plyometric exercises involve an eccentric muscle contraction immediately followed by a concentric contraction. After a PT period, a better use of the stretch-shortening cycle is obtained as an effect of the reduction in the time required for the transition from the eccentric to the concentric part of the jump [5], resulting in an increased ability of the muscles to develop maximum strength and explosive power. Our results are in good agreement with those found in previous investigations. Vassil and Bazanovk [38] reported a 10.15% increase in the vertical jump height after a low-intensity PT conducted with young female volleyball players, and Rojano et al. [8] observed a 9.3% increase in CMJ height and an 8.4% increase in CMJ peak power after a low intensity PT with young female volleyball players.

CMJ height and CMJ peak power also increased in the EXP group (13.68 and 9.75%, respectively) and, although no significant differences between groups were observed, the ES were moderate, indicating that PT + WBES combined program might be more effective for the improvement in vertical jump performance. These findings may be explained by the fact that voluntary exercise and electrical stimulation preferentially recruit different fiber types, which leads to a greater total amount of exercise [39]. In addition, our stimulation frequency was of 120 Hz, and according to Martínez-López et al. [19], the superimposed WBES is only effective when the stimulation frequency is higher than 85 Hz.

Both CON and EXP groups experienced significant improvements in 20 m sprint-time. An 8.71% decrease was observed in the CON group, with a large ES. Since PT produced an increase in CMJ height, the improvement in 20 m sprint-time was expected, because it has been frequently observed in previous literature that CMJ height has a strong association with short-sprint performance [40,41]. However, the decrease was of only 4.83% in the EXP group and the ES was moderate. Our findings appear to contradict those obtained by Benito-Martínez et al. [20] and Benito-Martínez et al. [21], who observed a higher decrease in 30 m sprint-time when electrostimulation was superimposed with PT. These differences may be explained by two main reasons: on the one hand, our PT + WBES combined program was actually performed only once a week; on the other hand, the PT carried out by those authors was actually of lower intensity than ours, with only 48 contacts per session. Therefore, the results from those two studies cannot be compared with ours and future research with similar trainings is needed.

To our knowledge, no studies have measured the effects of PT on handgrip strength. Our CON and EXP groups showed a significant increase of 3.93% and 4.38%, respectively, but ES were minimal. Since the trainings performed involved primarily the muscles of the lower limbs, these minimal increases were expected, and call into question that handgrip strength is an effective tool for predicting muscular strength of the lower limb, as suggested by Matsudo et al. [29] or Vaydya and Nariya [30].

The main limitation of this study is that post-test measures were carried out the week after the intervention period, and it seems that electrostimulation should be followed by a short period of sport-specific training to take full benefit of the electrostimulation application [42]. Similar research addressing this limitation is warranted.

Conclusion

Both traditional PT and PT + WBES combined program demonstrated to be a good strategy to improve CMJ performance and 20 m sprint-time. The most effective training method for improving CMJ performance was PT + WBES combined program, even when WBES was simultaneously combined with PT only one of the three training days in the week. However, traditional PT obtained better results in 20 m sprint-time. Both training methods produced minimal increases in handgrip strength, which indicates that handgrip strength may not be a good predictor of muscular strength and power of the lower limb, at least for athletes that have already been involved in PT.

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