Original Article

Effects of combined electrostimulation and plyometric training on vertical jump and speed tests

ELISA BENITO-MARTÍNEZ[1], AMADOR J. LARA-SÁNCHEZ[1] ✉, DANIEL BERDEJO-DEL-FRESNO[2], EMILIO J. MARTÍNEZ-LÓPEZ[1]

[1]Research Group HUM653 Laboratory. Dep. Didactic of Musical, Plastic and Corporal Expresions. University of Jaén, Spain

[2]England National Futsal Team and Manchester Futsal Club, Manchester, United Kingdom

ABSTRACT

Benito-Martínez E, Lara-Sánchez AJ, Berdejo-del-Fresno D, Martínez-López EJ. Effects of combined electrostimulation and plyometric training on vertical jump and speed tests. *J. Hum. Sport Exerc.* Vol. 6, No. 4, pp. 603-615, 2011. The aim of this study was to determine the performance evolution of a group of athletes after 8 weeks of training that combined electrostimulation (NM ES) and plyometrics (PT). 78 medium level sprinter athletes participated, 40 women and 38 men (age, 15.9±1.4 years old, body mass index, 20.5±1.68 kg/m^2; weight 58.53±8.05 kg; height, 1.68±0.07 m). The sample was randomized into four groups [Control (PT only), NM ES + PT, PT + NM ES, and Simultaneous (plyometric jumps were performed through the passage of current). Improvements were obtained in the Abalakov jump of 3.57% (p<0.01), 13.51% (p<0.001), 1.23% (p<0.01), and 0.77%, and in the sprint of 0.45%, 3.87% (p<0.05), 4.56% (p<0.01) and 7.26% p<0.001 for the control group, NM ES + PT group, PT + NM ES group, and Simultaneous group, respectively. It was concluded that a) improvement in vertical jump requires the application of the NM ES prior to PT; b) the sprinter athlete must combine the workout simultaneously or apply the ES after the PT training; and c) in sportspeople that require improvement in both the vertical jump and speed tests (e.g. basketball) the simultaneous method is not recommended, the order of application of NM ES and PT being non-determinant. Finally, the time needed to obtain significant improvement in strength training through a combination of NM ES and PT is substantially lower (15 days) than the time needed to improve speed (30 days). Key words: ELECTROSTIMULATION, PLYOMETRICS, MUSCLE STRENGTH, ABALAKOV JUMP, SPEED 30 M LAUNCHED.

✉ Corresponding author. University of Jaén. Dep. Didactic of Musical, Plastic and Corporal Expresions. Faculty of Humanities and Education Sciences (D-2, 143). P. Las Lagunillas. 23071, Jaén. Spain.
E-mail: alara@ujaen.es
Submitted for publication September 2011
Accepted for publication October 2011
JOURNAL OF HUMAN SPORT & EXERCISE ISSN 1988-5202

doi:10.4100/jhse.2011.64.04

INTRODUCTION

Neuromuscular electrostimulation (NM ES) consists on applying an electric current on the muscle or peripheral nerve in order to provoke its involuntary contraction (Lake, 1992). Its use for the training of athletes has as a main advantage a higher increase in force than in voluntary training (VT) (Maffiuletti et al., 2002; Brocherie et al., 2005; Babault et al., 2007). However, its main disadvantages lie in the inhibition of the myotatic reflex and Golgi organ tendon during its application, thereby increasing the risk of injury if their use is not adequate (Raquena et al., 2005; Jubeau et al., 2006), and secondly in the athlete's inability to obtain improved agonist-antagonist muscle coordination (Holcomb, 2005; Paillard, 2008).

In the last two decades, training with NM ES to develop lower body power in athletes has been successfully used by authors such as Babault (2007) and Maffiuletti (2002), which obtained improvements of 2.4% and 5.8% in Drop Jump (DP), respectively. Similarly, they found incremental improvements of 2.4% (Herrero et al., 2006) and 5.8% (Brocherie et al., 2005) in 20-meter and 50-meter sprint, respectively.

Moreover, the term Plyometrics (PT) was first used in 1975 by Wilt (Chu, 1999). Its Latin root plyo + metric stands for “measured increase” and consists of the muscular use of the movement eccentric phase prior to its concentric contraction. This method offers several advantages such as the increase in jumping ability and the improvement of intramuscular coordination (Kotzamanidis, 2006; Markovic et al., 2007). Likewise, it does not show any significant disadvantages for the athlete, as long as it is not used in a state where a strong mechanical muscle overload is not recommended, i.e. in periods of detraining and overtraining, after an injury, or during the time before immediate competition (Lehance et al., 2005; Takano et al., 2010). For several decades, most of the results obtained in athletes after plyometric training have provided high efficiency and significantly, since both explosive and reactive strength improve (Verkhoshansky, 1999; Herrero et al., 2006; Markovic et al., 2007; Maffiuletti, 2008; Arazi & Asadi, 2011).

Although previous evidence has confirmed that strength training in isolation, either by NM ES or PT, can offer high efficiency on the explosive and explosive-elastic-reactive force manifestation, the combined effect of both is not known. It was found that the physiological adaptations produced in the combined therapy are much greater than those that occur in isolated therapies such as NM ES or VT - (Vanderthommen & Crielaar, 2001; Kotzamanidis, 2006). However, the combined use of NM ES and PT has not been commonly used previously (Maffiuletti et al., 2002; Herrero et al., 2006). Furthermore, the combined use has been employed mainly to benefit from performance in tests on lower limb power as a DJ, Countermovement Jump (CMJ) and Squat Jump (SJ) (Maffiuletti et al., 2002), but less so in speed (Herrero et al., 2006).

In order to evaluate the previous demonstrations of force in the extensor muscles of the lower limbs sprint and vertical jump tests (Berdejo & González, 2009; Martínez-López et al., 2009; Riggs & Sheppard, 2009) have often been used. Currently, race tests to measure the explosive-elastic-reactive force involving a limited muscle amplitude show high validity and reliability due to the use of photocells. Besides, the vertical jump tests are standardized, as well as simple to implement, and there is enough information according to the various sporting disciplines. However, the need for more reliable data has encouraged the use of contact platforms that allow to obtain indicators to evaluate the explosive demonstration of force (Lara et al., 2006; Juárez et al., 2008).

The aim of this study was to determine the evolution of physical performance after 8 weeks of NM ES and PT training. Particularly, it sought to know the possible differences between performance in speed and jumping, derived from combined NM ES and PT training, performed with different implementation protocols. It was hypothesized that the order of application of NM ES and PT during training had different effects depending on the needs of the athletic event.

MATERIAL AND METHODS

Experimental approach to the problem

This is a quantitative study of a duration of 8 weeks where 4 measures (M_1 = initial measure, M_2 = 2nd week, M_3 = 4th week, and M_4 = 8th week) were made. The dependent variables were the vertical jump height and the running time, which were taken through the Abalakov test and the 30-meter sprint launched test. The independent variable was the training method.

Subjects

78 mid-level athletes participated in this study, 40 women and 38 men from speed disciplines (100 and 200-meter dash and 100 and 110-meter hurdles). The group characteristics were the following: they were aged 15.9±1.4, had a Body Mass Index (BMI) of 20.5±1.68, a weight of 58.53 ± 8.05 kg, and a height of 1.68±0.07 m. The average time that participants had been training in their discipline was 5.64±2.13 years. Athletes had not previously experienced electrical training.

Procedures

The weight and height of the participants were measured with a 100-milligram sensitivity scale and a 1-millimeter sensitivity tape measure SECA (SECA Ltd, Germany). The Body Mass Index (BMI) was calculated using the Quetelec formula: BMI = weight (kg) / height (m^2). Two photoelectric cells Eleiko Sport MAT RS 232 (United Kingdom) were employed to record the times of the 30-meter sprint launched test. The jump tests were recorded with a jump contact platform PSION ORGANISER 2 CM (British). Also an electrostimulator Megasonic P4 313 Sport of Medicarim (Spain) was used for the electrostimulation training. Athletes were distributed through a simple random probability sampling. The distribution and treatment of the four groups was as follows:

Group 1 (Control): made up of 20 athletes (9 women and 11 men) aged 17.05±1.47, with a BMI of 20.0±1.5. These athletes performed the planned plyometric jumps twice a week and received as a placebo a Type TENS analgesic current. The athletes were never informed of the type of current applied to eliminate potential mistakes derived from this fact. Both NM ES and TENS were applied through the same electrotherapy device and the TENS current was applied in a pulsating way to obtain muscular contraction. This way, although the NM ES current had the purpose of developing strength, the TENS current was merely analgesic. However, the athletes perceived muscular contraction in both cases, thus avoiding any potential mistakes derived from the athletes' awareness of the type of current applied.

Group 2 (NM ES + Plyometrics): comprised by 20 athletes (11 women and 9 men) aged 17.65±1.47 and with a BMI of 20.7±1.3. In the first place, this group received the ES training and later did the plyometric jumps protocol (Figure 1).

Figure 1. Application of electrostimulation to the athlete before plyometric training [Group 2: NM ES + PT] and after plyometric training [Group 3: PT + NM ES].

Group 3 (Plyometric + NM ES): consisting of 19 athletes (10 women and 9 men) aged 16.16±1.72 and with a BMI of 20.5±2.2. In this case, the athletes did the plyometric jumps first and then 12 min of NM ES were applied.

Group 4 (Simultaneous): made up of 19 athletes (10 women and 9 men), aged 17.7±1.49 and a BMI of 20.7±1.6. This group did the combined training, which consisted on doing the same protocol of plyometric jumps as the other groups, together with the simultaneous application of NM ES. In other words, the athletes jumped when they felt the electrical current and had their rest time when the current was not applied (Figure 2).

Figure 2. Combined training with plyometric jumps and electrostimulation [Group 4: Simultaneous].

Electrostimulation protocol

The search for an ideal NM ES training protocol has led to the use of a wide variety of electrical current parameters. More recent studies have allowed to establish as the most appropriate use a stimulus frequency of between 120 and 150 Hz, a pulse width of between 0.30 and 0.40 s, a ratio of pulse time and resting time of 1:3 and 1:4, and a treatment duration of between 10 and 15 min (Maffiuletti et al., 2002; Brocherie et al., 2005; Herrero et al., 2006; Babault et al., 2007). Regarding the applied current intensity, which is measured by the percentage of maximal isometric voluntary contraction, the established range has been very wide, being used from 50% (Child et al., 1998) up to 100% (Delitto et al., 1989), or even maximum intensities tolerated by athletes (Brocherie et al., 2005; Herrero et al., 2006).

The current parameters used were: frequency of 150 Hz, a pulse width of 0.35 s, a time of contraction-rest of 3-12 s, a dosage of 2 days / week and a total time of 12 min application. The current intensity applied was the maximum tolerated by the athlete, which corresponded to an average intensity of 26.39±7.11 and 26.22±5.88 mA in men and women, respectively.

Plyometric protocol

The plyometric protocol consisted on the following exercises:

1st Exercise: it consisted of two sets of 8 repetitions each of maximum jumps raising the knees towards the chest. Small bounces were not allowed in the landing, the jump's impact absorbing stage being the eccentric phase of the next jump. As for the Simultaneous group, this exercise was done isolatedly, that is, without superimposing the electric current, since it was impossible to meet the required recovery time of the electrical impulse between jumps.

2nd Exercise: it consisted of two series of jumps of 8 repetitions each starting from a squatting position (flexion of knees and hips while maintaining a clearance angle of flexion but always wider than 100°), where three small jumps were done before the fourth maximum jump. Athletes could help themselves with their upper limbs momentum. The landing jump had to be done in situ, and three small jumps were performed again. In the Simultaneous group the athlete performed the maximum jump when they felt the electrical current.

3rd Exercise: it included 2 sets of 8 repetitions each. It contained the same steps as in the 2nd exercise, except that the landing jump was done with one of the lower limbs in an advanced position. Also, after the first little bounce, the feet came back to a parallel position to do the other two bounces from that position.

The athletes performed a 2-day familiarization period prior to training, where the plyometric jump technique was shown visually and repeatedly explained until they performed the exercises correctly. All athletes submitted their written informed consent and the study complied with the Declaration of Helsinki (rev. 2008).

Test application

Abalakov (ABK) tests and 30-meter sprint launched tests were repeated from the first day of the experiment until the end of it every two weeks, letting at least 48 hours of rest. As for the Abalakov test, there were two days of training during the week before the first tests, so that athletes became familiar with the jumps and with the aim to avoid the possibility of bias because of poor exercise technique. After a regulated warm-up, directed by the researcher, the athletes did the ABK jump test, which consisted of bending their knees from the standing position and without making stop motion, and then jumping as high as possible with the help of their upper limbs (González et al., 2006). Every athlete performed four maximum jumps and only the highest was recorded. The recovery time between sets was 1 min.

Two photocells were used to perform the 30 meters launched test, which were placed. 10 and 40 meters from the start, respectively. Athletes were advised that they should run as fast as possible from the start line to the second cell (Cometti, 2002). Every athlete performed this distance twice and only the best time was recorded. The athletes had a 3-minute rest period between both sprints (Vittori, 1990).

Statistical analysis

The statistical analysis was carried out using SPSS v. 19. The analysis of variance through repeated measures ANOVA with adjusted confidence interval by Bonferroni and Pearson bivariate correlation were done. The rejection criterion for establishing both the correlations and the significant differences was set at the conventional level of 0.05.

RESULTS

The vertical jump height in each group of athletes is shown in Figure 3. A 4 (group) x 4 (ABK jump) ANOVA of the ABK Tests found a training effect between the vertical jump and the different treatment groups (Control group, NM ES + PT group, PT + NM ES group, and Simultaneous group) F (9.222) = 6.31, effect size (η^2) = 0.20, which indicated that the jump height was different according to the different groups. More specifically, statistically significant differences were found between the measurements of the Control group [F (3.57) = 6.39, η^2 = 0.25], the NM ES + PT group [F(3.57) = 15.12, η^2 = 0.44] and the PT + NM ES group [F(3.54) = 6.10, η^2 = 0.25]. However, no differences were found in the Simultaneous group [F(3.54) = 0.96, η^2 =0.05].

Further analysis showed that the vertical jump highest performances were obtained in the group that applied NM ES before PT. These improvements (p<0.001) were significant from the first 15 days of training, continuing in the next two periods. Not so in the PT group that performed PT prior to NM ES, where despite a significant increase (p<0.001) in the first 15 days, there was a reverse progression that played down the benefits previously acquired. Nor did this happen in the Simultaneous group, where no significant differences between any of the measurements were found. Finally, the Control group experienced statistically significant improvements in jump height, especially from the first month of training.

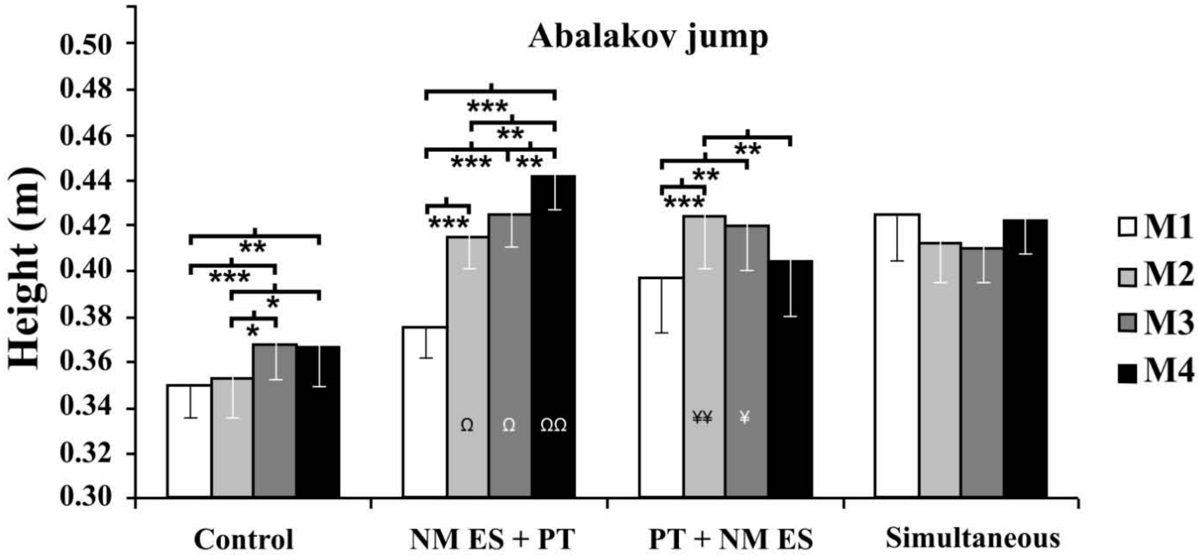

*Figure 3. Graphic shows the height of Abalakov jump, M_1 (initial), M_2 (2nd week), M_3 (4th week) and M_4 (8th week). Effect produced in each group of athletes: *p<0.05, **p<0.01, ***p<0.001. The intergroup effect is shown as: Ω, and ΩΩ denote p<0.05 and p<0.01 compared with Control group respectively on same measure. ¥ and ¥¥¥ denote p<0.05 and p<0.01 compared with Control group respectively on same measure.*

The intergroup analysis confirmed the existence of significant differences according to the training method used [F (3.74) = 2.82, η2 = 0.10]. The group that performed NM ES before PT obtained the greatest and most progressive improvements compared to the Control group [M_2 = (Mean = 0.41±0.06 and 0.35±0.08 m, *p*<0.05)] for NM ES + PT and Control respectively; [M_3 = (Mean = 0.42±0.06 and 0.36±0.06 m, *p*<0.05)] and [M_4 = (Mean = 0.44±0.06 and 0.36±0.07 m), *p*<0.01)]. Although the group that trained in reverse way (PT + NM ES) improved significantly (*p*<0.01) compared to the Control group during the first 15 days of training (M_2), a regression effect in M_3 and M_4 was obtained, with a progressive loss of benefits as the training progressed. It is important to report that the intergroup analysis of Abalakov test showed previous (M_1) significant differences (*p*<0.01) only between the Control group and the Simultaneous group.

The time used to run the 30-meter distance in each group of athletes is shown in Figure 4. A 4 (group) x 4 (30-meter sprint launched) ANOVA found a training effect between the results of the 30-meter sprint launched test and the different treatment groups [F (9.222) = 3.43, η^2 = 0.12]. More specifically, statistically significant differences were found between the measurements of the NM ES + PT group [F (3.57) = 4.41, η^2 =0.19], those of the PT + NM ES group [F (3.54) = 12.13, η^2 = 0.40], and of the Simultaneous group [F (3.54) = 34.76, η^2 = 0.66]. No differences were found in the Control group [F (3.57) = 0.02, η^2 = 0.001].

Further analysis showed that the best performances in the 30-meter sprint launched were obtained in the group where PT was applied prior to NM ES (*p*<0.01) and especially in the group of athletes who trained NM ES and PT (*p*<0.001) simultaneously. Although significant improvements (*p*<0.05) were also seen in athletes who had trained ES previously, the former occurred only after the first month of training, coming to a halt in the subsequent records M_3 and M_4. In the Control group no changes were appreciated in the speed of participants regarding any of the measures.

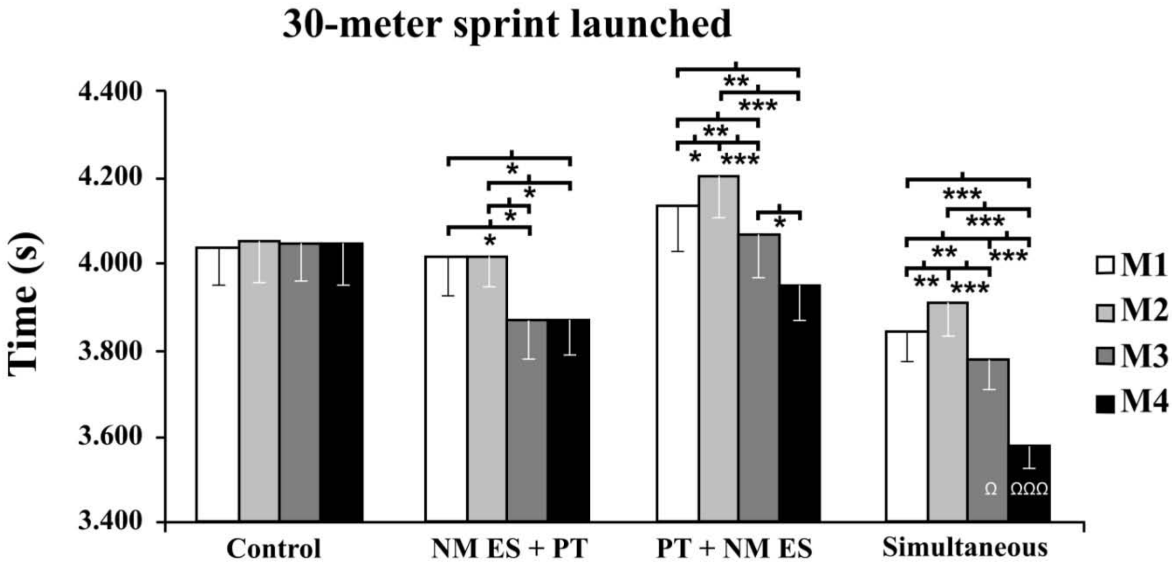

*Figure 4. Graphical representation of the measures of time spent in 30-meter sprint launched test, M_1 (initial), M_2 (2nd week), M_3 (4th week) and M_4 (8th week). Effect produced in each group of athletes: *p<0.05, **p<0.01, ***p<0.001. The intergroup effect is shown as: Ω, and ΩΩΩ denote p<0.05 and p<0.001 respectively compared with Control group on same measure.*

The intergroup analysis in 30-meter sprint launched test, showed the existence of significant differences according to the training method used [F (3.74) = 31, η2 = 0.11]. Only athletes who trained simultaneously obtained significant improvements in speed from the first month (M_3) (M = 3.77±0.31 s, *p*<0.05) compared to the Control group (M = 4.04±0.39 s), further enhancing (*p*<0.001) in M_4 (Simultaneous group = 3.57±0.21 s, and Control group = 4.05±0.43 s). It is necessary to report that in the intergroup analysis the 30-meters sprint launched test showed previous (M_1) significant differences (*p*<0.05) only between the PT + NM ES group and the Simultaneous group.

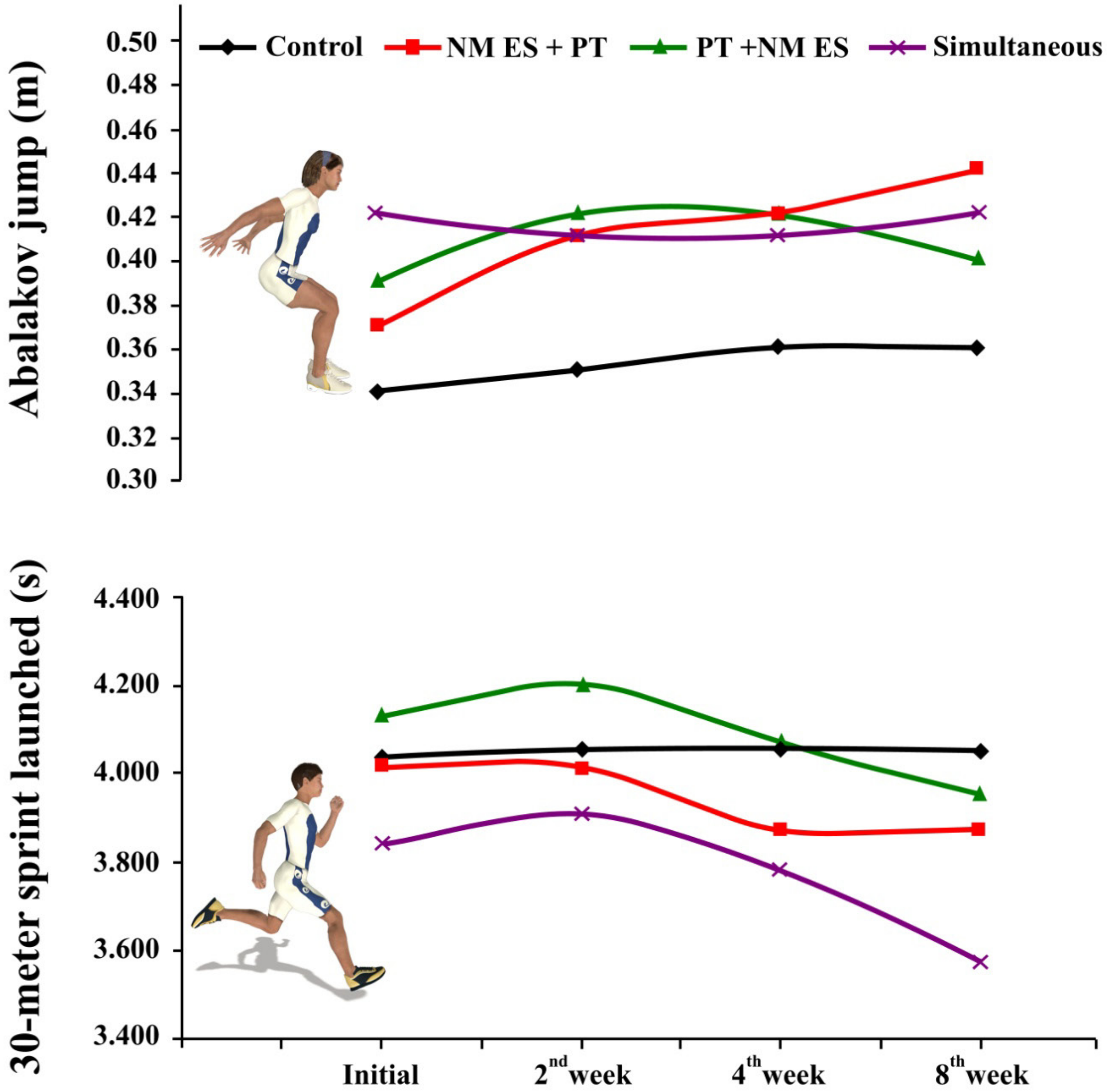

Figure 5. Effect of different training methods for eight weeks. Smoothed curves. PT training from the previous stimulation of the muscle fiber by NM ES improves significantly the vertical jump (p<0.05), but does not translate immediately into increase of the athlete's speed. Simultaneous training does not cause significant improvements in vertical jump, but in the 30-meter sprint launched test (p<0.05).

DISCUSSION AND CONCLUSIONS

Next, some aspects of interest relating to combined NM ES and PT training will be discussed, as well as their suitability to improve both strength and speed. The results analysis in the Abalakov jump tests allowed to report three main aspects. First, the application of NM ES pre-training prior to PT causes a more progressive and greater improvement than that of the other combinations (13.51%), since the overstimulated muscle (Jubeau et al., 2006) is more active and receptive, allowing the subsequent performance of plyometric exercises at greater intensity and, therefore, there would be a higher training overload.

Secondly, if both methods are applied in reverse order (PT + NM ES) the jump improvements are lower (1.23%) and less steady, obtaining a progressively worsening effect on the jump and loss of the acquired improvements during the first weeks. And finally, the simultaneous application of PT and NM ES slows down the improvement (0.77%) in the athlete's jumping ability. In this case, it is believed that muscle tension during the current application does not allow a full movement of extension in every bound, and more importantly, the disruption of every jump, due to the need to reach the current adjustment, would prevent the benefit of the eccentric phase between jumps and consequently the benefit of training the former.

Moreover, regarding the 30-meter sprint launched test, the highest performance was obtained in the athletes who performed PT prior to NM ES (4.56%), and especially those who exercised simultaneously (7.26%). Although both groups showed a worsening effect on the results after the first 15 days (M_2), later they took better advantage of supercompensation until they achieved a considerable and progressive increase in performance from the first month of training. Unlike them, the group that used NM ES previously showed that, although there was a significant improvement ($p<0.05$) during the training period (3.87%), this occurred later (M_3) and without any progression.

In order to understand the above mentioned counter effects on the results of both tests, we should first isolate the obtained performances of our athletes in each training method, especially the PT training that does not include the application of electrostimulation. Although most authors consider that PT is effective to improve jump height (Bobbert, 1990; Yanagi et al., 2003), others suggest that the positive effects are not significant (Herrero et al., 2006; Markovic et al., 2007), and even cause adverse effects (Luebbers et al., 2003). In the PT group significantly improvements ($p<0.01$) of 3.57% were seen in the Abalakov jump. These results are lower than the averages reported by Markovic (Herrero et al., 2006) between different types of vertical jumps SJ, DJ and CMJ with 6.9%, and similar to 3.6% in SJ by Tricoli et al. (2005). However, in the same group a total stagnation in the time of 30-meter sprint launched test was found. This confirms that PT training causes a disparate impact on the athletes' improvement similar to that found in other studies that showed improvements in the sprint phases (Kotzamanidis, 2006) but not in the acceleration phase (Herrero et al., 2006). It has been evidenced that greater jumping ability does not involve any increase in the athlete's speed, as the moderate correlations between the measures of both tests have shown (r= -0.65, r= -0.59, r= -0.68, and r= -0.57, $p_s<0.01$) in M_1, M_2, M_3 and M_4 respectively. Therefore, the speed improvements gained in the other groups would be determined primarily by the effect of NM ES and not by PT training.

On the other hand, isolated NM ES training has offered clear benefits, as concluded by Billot et al. (2010), who after five weeks of NM ES training obtained not only improvements in vertical jump and speed, but also in ball skills in soccer players. Furthermore, although the benefits of exclusive NM ES training need a minimum intensity threshold of at least 8 sessions to induce strength development (Miller & Thepautmathieu, 1993), through the use of combined training the present study has obtained significant increases in strength and speed from the first 4 and 8 training sessions, respectively.

As deduced from our results, the combined NM ES and PT training has been an important benefit in the athletes' strength and speed, confirming that the order of implementation is crucial in terms of the ability to be developed (Figure 5). Some answers about the causes for the above results could be found in previous studies that have used NM ES in combination with VT. For example, at a therapeutic level hybrid training (NM ES + VT) has been proved to be the most effective for maintaining and increasing the muscle volume and extensor strength in different body limbs in both elderly (Takano et al., 2010) and bedridden patients or astronauts in outer space (Martínez-López et al., 2009). In addition, more muscle adaptations were made in athletes, since NM ES + VT can facilitate the training accumulative effects and causes an improvement in the performance of complex dynamic movements (Paillard, 2008). However, the main aspects related to the differences in performance of the jump and speed tests in this study could be related to the effects produced by fatigue and motor control.

Thus, pre-training fatigue (NM ES + PT) allowed to overload and localize muscle training so that the effect was more focused on the muscle power which was necessary in the jump, where the technical role was relegated to the purely muscular role, the latter being more suitable for beginners (Cometti, 2002). However, if NM ES is combined with VT or PT training (post-fatigue), it will not increase the recruitment of motor units (Paillard et al., 2005) but will not damage the postural control either, creating a positive change in the contribution of proprioceptive information (Paillard, 2008) and thereby achieving significant improvements in speed. Finally, the monitoring of the athletes during the implementation showed that the Simultaneous group focused more on getting the coordination required to perform successful plyometric jumps during the current application than on jump height itself. In this sense, the results were consistent, since jump height did not vary but excellent speed times were found due to an increase in the coordination between agonist and antagonist muscles, thus facilitating the learning of specific coordination of the complex movements in the race.

The present results must be treated with caution, because although a sample higher than usual was used to avoid conflicting results (Markovic et al., 2007), many factors that can strongly influence the effects of the intervention still coexist. For example, derivatives of the training design (type of exercise, volume and intensity of training, weekly frequency, training time and daily rest), characteristics of the participants (gender, age, years of training), psychological factors (motivation for training, suffering capacity or effort) and qualitative aspects related to the execution techniques. Also, the performance evolution after the interruption of the treatment is not known, for a period of two weeks would be needed to complete the assessment.

In conclusion, combined NM ES and PT training has shown different effects depending on the physical type or requirements demanded in each athletic event. Its application in a single session can provide both positive and negative effects. NM ES training can be used to supplement PT training, since it notably increases vertical jumping ability as well as the athlete's speed. However, its usefulness is determined by the order of application during the training session.

The improvement in vertical jump test requires the use of NM ES prior to PT. Failure to do so, the application of NM ES would be contraindicated because there would be fewer benefits than those caused by a unique PT training. On the other hand, the improvement in the 30-meter sprint launched test requires to perform combined NM ES and PT training simultaneously or applying NM ES after PT training. Furthermore, if the aim is to achieve improvements in both vertical jump tests and speed tests, the order of application of NM ES and PT is irrelevant, although the simultaneous method is not advised.

Finally, with regard to the time required to achieve improvements in these tests with combined NM ES and PT training, it should be substantially lower in the jump test than in the sprint test.

ACKNOWLEDGEMENTS

We would like to express our gratitude to Spanish translator and interpreter Andrea Pérez-Arduña for the translation into English and style correction of the present paper.

REFERENCES

1. ARAZI H, ASADI A. The effect of aquatic and land plyometric training on strength, sprint, and balance in young basketball players. *J Hum Sport Exerc.* 2011; 6(1):101-111.doi:10.4100/jhse.2011.61.12 [Back to text]
2. BABAULT N, COMETTI G, BERNARDIN M, POUSSON M, CHATARD J. Effects of electromyostimulation training on muscle strength and power of elite rugby players. *J Strength Cond Res.* 2007; 21:431-437. [Abstract] [Back to text]
3. BERDEJO D, GONZÁLEZ JM. Strength training in young tennis players. *J Sport Health Res.* 2009; 1:46-55. [Full Text] [Back to text]
4. BILLOT M, MARTIN A, PAIZIS C, COMETTI C, BABAULT N. Effects of an electrostimulation training program on strength, jumping and kicking capacities in soccer players. *J Strength Cond Res.* 2010; 24:1407-1413. doi:10.1519/JSC.0b013e3181d43790 [Back to text]
5. BOBBERT MF. Drop jumping as a training method for jumping ability. *Sports Med.* 1990; 9:7-22. doi:10.2165/00007256-199009010-00002 [Back to text]
6. BROCHERIE F, BABAULT N, COMETTI G, MAFFIULETTI N, CHATARD JC. Electrostimulation training effects on the physical performance of ice hockey players. *Med Sci Sports Exerc.* 2005; 37:455-460.doi:10.1249/01.MSS.0000155396.51293.9F [Back to text]
7. CHILD RB, BROWN SJ, DAY SH, SAXTON JM, DONNELLY AE. Manipulation of knee extensor force using percutaneous electrical myostimulation during eccentric actions: Effects on indices of muscle damage in humans*.* *Int J Sports Med.* 1998; 19:468-473. doi:10.1055/s-2007-971946 [Back to text]
8. CHU D. *Ejercicios Pliométricos*. Barcelona: Paidotribo; 1999. [Abstract] [Back to text]
9. COMETTI G. *El entrenamiento de la velocidad*. Barcelona: Paidotribo; 2002. [Abstract] [Back to text]
10. DELITTO A, BROWN MJ, STRUBE SJ, ROSE LECHMAN RC. Electrical stimulation of quadriceps femoris in an elite weight lifer: A single subjects experiment. *Int J Sports Med.* 1989; 10:187-191. doi:10.1055/s-2007-1024898 [Back to text]
11. GONZÁLEZ JM, MACHADO L, NAVARRO FJ, VILAS-BOAS JP. Acute affects of strength training from heavy loads and static stretching training on squat jump and countermovement jump. *Rev Int Cienc Deporte.* 2006; 2:47-56. [Full Text] [Back to text]
12. HERRERO J, IZQUIERDO M, MAFFIULETTI N, GARCÍA-LÓPEZ J. Electromyostimulation and plyometric training effects on jumping and sprint time. *Int J Sports Med.* 2006; 27:533-539. doi:10.1055/s-2005-865845 [Back to text]
13. HOLCOMB WR. Is neuromuscular electrical stimulation and effective alternative to resistance training? *Strength Condit J.* 2005; 27:76-79. [Back to text]
14. JUÁREZ D, NAVARRO F, ACEÑA RM, GONZÁLEZ JM, ARIJA A, MUÑOZ V. Relación entre fuerza explosiva en squat y acciones de salto, sprint y golpeo de balón. *Rev Int Cienc Deporte.* 2008; 4:1-12. [Full Text] [Back to text]
15. JUBEAU M, ZORY R, GONDIN J, MARTIN A, MAFFIULETTI NA. Late neuronal adaptations to electrical stimulation resistance training of the plantar flexor muscle. *Eur J Appl Physiol.* 2006; 98:202-211. doi:10.1007/s00421-006-0264-z [Back to text]
16. KOTZAMANIDIS C. Effect of plyometric training on running performance and vertical jumping in prepubertal boys. *J Strength Cond Res.* 2006; 20:441-445. [Abstract] [Back to text]
17. LAKE D. Neuromuscular electrical stimulation. *Sports Med.* 1992; 13:320-336. doi:10.2165/00007256-199213050-00003 [Back to text]
18. LARA AJ, ABIÁN J, ALEGRE LM, LINARES L, AGUADO X. Jump tests on a force platform for applicants to a sports science degree. *J Hum Mov Stud.* 2006; 50:133-148. [Full Text] [Back to text]

19. LEHANCE, C, CROISIER, JL, AND BURY, T. Optojump system efficiency in the assessment of lower limbs explosive strength. *Sci Sports.* 2005; 20:131-135. doi:10.1016/j.scispo.2005.01.001 [Back to text]
20. LUEBBERS PE, POTTEIGER JA, HULVER MW, THYFAULT JP, CARPER MJ, LOCKWOOD RH. Effects of plyometric training and recovery on vertical jump performance and anaerobic power. *J Strength Cond Res.* 2003; 17:704-709. [Abstract] [Back to text]
21. MAFFIULETTI N, DUGNANI S, FOLZ M, DI PIERNO E, MAURO F. Effects of combined electrostimulation and plyometric training of vertical jump height. *Med Sci Sports Exerc.* 2002; 34:1638-1644.doi:10.1249/01.MSS.0000031481.28915.56 [Back to text]
22. MAFFIULETTI, N. Caution is required when comparing the effectiveness of voluntary versus stimulated versus combined strength training modalities. *Sports Med.* 2008; 38:437-440. doi:10.2165/00007256-200838050-00006 [Back to text]
23. MARKOVIC G, JUKIC I, MILANOVIC D, METIKOS D. Effects of sprint and plyometric training on muscle function and athletic performance. *J Strength Cond Res.* 2007; 21:543–549. [Abstract] [Back to text]
24. MARTÍNEZ-LÓPEZ EJ, LARA AJ, CACHÓN J, RODRÍGUEZ I. Characteristics, frequencies and type of physical exercise practiced by the adolescents. Special attention to the obese pupil. *J Sport Health Res.* 2009; 1:88-100. [Full Text] [Back to text]
25. MATSUSE H, SHIBA N, UMEZU Y, NAGO T, TAGAWA Y, KAKUMA T, NAGATA K, BASFORD JR. Muscle training by means of combined electrical stimulation and volitional contraction. *Aviat Space Environ Med.* 2006; 77:581-585. [Abstract] [Back to text]
26. MILLER C, THEPAUTMATHIEU, C. Strength training by electrostimulation conditions for efficacy. *Int J Sports Med.* 1993; 14:20-28. doi:10.1055/s-2007-1021140 [Back to text]
27. PAILLARD T, NOÉ F, PASSELERGUE P, AN DUPUI P. Electrical stimulation superimposed onto voluntary muscular contraction. *Sports Med*. 2005; 35:951-966. doi:10.2165/00007256-200535110-00003 [Back to text]
28. PAILLARD T. Combined application of neuromuscular electrical stimulation and voluntary muscular contractions. *Sports Med*. 2008; 38:161-177. doi:10.2165/00007256-200838020-00005 [Back to text]
29. RAQUENA B, PADIAL P, GONZÁLEZ-BADILLO JJ. Percutaneus electrical stimulation in strength training: An up data. *J Strength Cond Res.* 2005; 19:438-448. [Back to text]
30. RIGGS MP, SHEPPARD JM. The relative importance of strength and power qualities to vertical jump height of elite beach volleyball players during the counter-movement and squat jump. *J Hum Sport Exerc.* 2009; 3:221-236. doi:10.4100/jhse.2009.43.04 [Back to text]
31. TAKANO Y, HANEDA Y, MAEDA T, SAKAY Y, MATSUSE H, KAWAGUCHI T, TAGAWA Y, SHIBA N. Increasing muscle strength and mass of thigh in elderly people with the hybrid-training method of electrical stimulation and volitional contraction. *Tohoku J Exp Med.* 2010; 221:77-85. doi:10.1620/tjem.221.77 [Back to text]
32. TRICOLI V, LAMAS L, CARNEVALE R, CRIELAARD JM. Short-term effects on lower-body funcional power development weightlifting vs. vertical jump training programs. *J Strength Cond Res.* 2005; 19:433-437. [Abstract] [Back to text]
33. VANDERTHOMMEN M, CRIELAARD JM. Electromyostimulation en medicine du sport. *Rev Med Liege.* 2001; 56:391-395. [Abstract] [Back to text]
34. VERKHOSHANSKY Y. *Todo sobre el método pliométrico.* Barcelona: Paidotribo; 1999. [Abstract] [Back to text]
35. VITTORI C. El entrenamiento de la fuerza para el sprint. *Revista de Entrenamiento Deportivo.* 1990; 4:2-8. [Back to text]
36. YANAGI T, SHIBA N, MAEDA T, IWASA K, UMEZU Y, TAGAWA Y, MATSUO S, NAGATA K, YAMAMOTO T, BASFORD, JR. Agonist contractions against electrically stimulated antagonists. *Arch Phys Med Rehabil.* 2003; 84:843-848. doi:10.1016/S0003-9993(02)04948-1 [Back to text]