Journal of Physical Education and Sport ® (JPES), Vol. 22 (issue 7), Art 210, pp. 1668 - 1674, July 2022
online ISSN: 2247 - 806X; p-ISSN: 2247 – 8051; ISSN - L = 2247 - 8051 © JPES

Original Article

Alterations in co-activation around the ankle joint after specific training, do not affect vertical jumping kinematics and performance.

THEODOROS M. KANNAS[1], ATHANASIOS KATIS[2], FOTINI ARABATZI[3]
[1,2,3,] Laboratory of Neuromechanics, Department of Physical Education and Sports Sciences at Serres, Aristotle University of Thessaloniki, GREECE.

Published online: July 31, 2022
(Accepted for publication July 15, 2022)
DOI:10.7752/jpes.2022.07210

Abstract
The aim of this study was to examine the effects of ankle-specific plyometric exercises and electromyostimulation (EMS) on vertical jump biomechanics. Thirty participants were divided into three training groups: a) incline plyometrics group, b) plane plyometrics group and c) EMS group. Each group followed a 4 weeks training period. The plyometric training session consisted of eighty vertical hops as fast as the participants could while EMS training included eighty fast contractions in 15° plantar flexion. Take-off velocity (Vto) and sagittal kinematics of the hip, the knee, and the ankle joints were recorded and analyzed. The kinetics data were also analyzed before and after the intervention. The muscle activity of the medial gastrocnemius (MGAS) and the co-activation index between the Tibialis Anterior (TA) and the MGAS was recorded and evaluated during CMJ before and after training. A non-significant effect of training on Vto, sagittal kinematics, and muscle activity was observed for the training groups after the training period. In contrast, all the intervention groups were found to increase ground reaction forces and rate of force development significantly during the CMJ. Co-activation index was increased after plane plyometrics and EMS training for CMJ in contrast to the incline hopping. The present results indicate that specific ankle training could result in alterations of the dynamic parameters as well as in muscle co-activation during the CMJ after a four-week intervention. These changes do not include increases in the kinematics or vertical performance. The present results suggest that a longer training period is needed to observe significant changes in vertical jumping technique and performance.
.**Keywords: Ankle joint, Plyometric, Incline, electromyostimulation, Jumping biomechanics, co-activation**

Introduction

Power production is an important factor for success in sports since most of them involve sprinting and jumping actions. The majority of sports movements include high accelerating and velocity rates combined with short time contact with the ground. Thus, the produced force and power capacity of the plantar flexors is a determinant factor for the final performance either in the team or individual sports. Thus, it is important to use specific exercises which will improve plantar flexors' explosive capacity (Toumi, Best, Martin & Poumarat, 2004).

Previous studies (Azreh et al., 2020; Arabatzi, Kellis, Saez Saez De Villarreal, 2010; King & Cipriani, 2010) have shown that plyometric training consisting of many different exercises could result in increased jumping ability as well as changes in joint kinematics. Azhre et al. (2020) showed that a specific plyometric protocol focused on knee extensors increased CMJ height due to greater extension of the hip and the knee. The extension velocity of these joints was also increased. Similarly, Arabatzi et al. (2012) have also shown that plyometrics training increased both SJ and CMJ height. The authors proposed that the increases in SJ height were due to the different neural activation after the training. Moreover, increased knee flexion was responsible for the increases in CMJ height. Although previous studies have shown that it is possible such training might affect knee biomechanics, it is not clear if an ankle-specific plyometric protocol could result in ankle biomechanics or jumping height.

Hopping is a jumping exercise, which is usually used during plyometric training to increase plantar flexors' power production. It has been found that hopping is effective only in a training program that includes a variety of jumping exercises. It is possible that hopping does not provide sufficient stimulus to the muscles of lower limbs to increase their capacity in a short training period (Kannas, Kellis & Amiridis, 2012). In contrast, it was found that incline hopping might be more effective to increase specific jumping ability due to alterations in deep aponeurosis properties and better use of the force-length relationship of the plantar flexors (Kannas et al., 2012). These previous findings categorized incline hopping as a specific exercise for the plantar flexors. However, the effects of incline hopping on biomechanical parameters of jumping performance have not received the appropriate attention.

Both whole-body (WB-EMS) and isometric electromyostimulation (EMS) is a training method that has been used to increase muscle strength ((Pano-Rodriguez, Bletran-Garrido, Hernadez-Gonzalez and Reverter-

Corresponding Author: . THEODOROS M. KANNAS, E-mail: thkannas@phed-sr.auth.gr

Masia, 2019; Filipovic, Kleinoder, Dormann & Mester, 2012). Wirtz et al., (2019) concluded that the use of WB-EMS could be beneficial for strength qualities while limited effects were found in multi-joint actions such as vertical jumps and sprints. In EMS training, Maffiuletti, Pensini and Martin (2002) have shown increased plantar flexors' strength due to increased muscle activation. Moreover, Maffiuletti et al. (2000) and Malatesta, Cattaneo, Dugnani and Maffiuletti (2003) showed that EMS (combined with plyometrics) increased the jumping ability of basketball and volleyball players, respectively. The aforementioned studies have shown that isometric EMS training increased squat jump (SJ) performance in both trained subjects and elite athletes. Similar results have been reported for countermovement jumps (CMJ) and drop jumps (DJ) in elite athletes (Babault, Cometti, Bernardin, Pousson & Chatard, 2007). However, the effects of EMS training on jumping biomechanics have not been extensively examined.

Although incline hopping and EMS have been found to be specific enough to increase plantar flexors' performance, their effects on jumping biomechanics have not been studied. Therefore, the purpose of this study was to compare the effects of these specific training exercises on the biomechanical parameters and the final performance of vertical jumping.

Material and methods

Participants

Thirty active male students (age: 17.3±1.5 years, height: 169.7±5.3cm, weight: 66.9±6.2 kg), participated in this study. Approval for the experiment was obtained from University Ethics Committee on Human Research. All the participants did not involve in any particular strength and/or plyometric training program over the last 6 months.

Procedure

Participants were randomly assigned to the incline hopping (IH) group (n = 10), the plane hopping (PH) group, and the electromyostimulation (EMS) group (n = 10). A total of 16 sessions (four sessions/week) were performed by the experimental groups.

The IH and PH performed one session, to be familiarized with the jumping technique. Each plyometric training session was divided into three phases: a) The warm-up phase, which included jogging and stretching exercises. b) The main phase, which included 8 sets of 10 maximum jumps, with a 2 min rest. During the main phase, the IH group performed hopping on an inclined (15º) ramp (as shown in Figure 1). The PH group performed hopping on a plane ramp. Special attention was given to executing the jumps "as fast and high as possible". c) The recovery phase included 5 min stretching.

The EMS group also participated in one session to be familiar with stimulation. They completed sixteen 30-minute sessions of isometric bilateral EMS (Myostim, Medicompex, Ecublens, Switzerland) over the training period. Eighty isometric contractions were performed during each training session. The participants were standing against the wall with the ankle at -15º (dorsi flexion), knee fully extended, while the hands touched the wall (as shown in Figure 1). Each session was preceded by a standardized warm-up consisting of 5 min of submaximal EMS (5 Hz; pulses lasting 200 msec). The two positive electrodes (5 x 5 cm) were placed over the superficial aspects of the medial (MGAS) and lateral gastrocnemius (LGAS) while the negative electrodes (10 x 5 cm), were placed over their muscles' bellies. Each 4-sec contraction was followed by a pause lasting 20 sec. Intensity (range 0–100 mA) was monitored online and was gradually increased to a level of maximally tolerated intensity depending on the subjects' threshold.

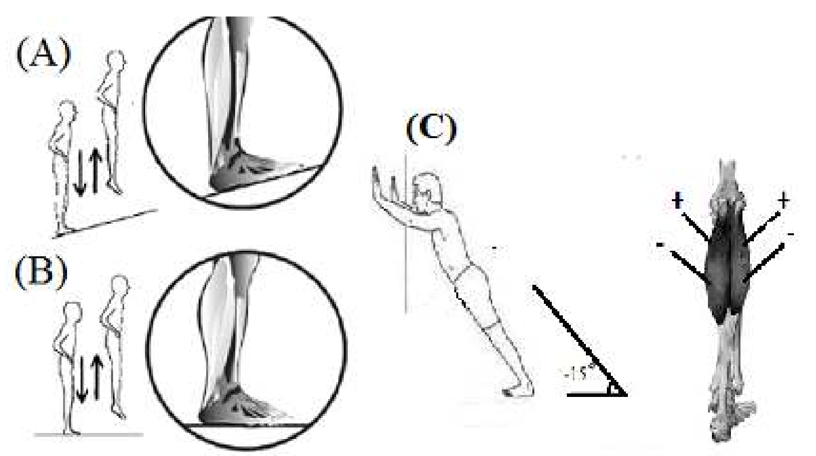

Figure 1. Hopping on an incline ground (A), hopping on a plane ground (B) and electromyostimulation training where the participant's knees were fully extended while the ankles joints were 15° dorsi flexed (C)

Data collection and analysis

Jumping ability

The participants performed 3 maximum SJ and CMJ after a standardized warm-up routine on a customized uni-axial force plate (60 9 40 cm) before and after the training period. The platform uses a strain gauge (Model LC4204—K600, A&D Co. Ltd., Japan) capable to measure vertical ground reaction force (Fz). The best jumps were used for further analysis. Rate of force development (RFD) was calculated as the maximum value of the first derivative of the Fzmax from the time that Fz exceeded body weight until the Fzmax (Arabatzi et al., 2014).

Kinematics

Kinematic data were collected with the 3-D Vicon motion analysis system (Oxford Metrics Ltd., Oxford, UK). The camera was calibrated to a volume of 2.0 m3 and calibration errors were all below 3 mm. Kinematic data were sampled at 120 Hz. Retroreflective spherical markers were placed on selected anatomical landmarks: the head of the 5th metatarsal, lateral malleolus, lateral femoral epicondyle, greater trochanter and acromion. A standing trial was recorded to establish initial joint angle conditions. The resulting displacement - time data of each marker were filtered using a low-pass, two-order, Butterworth, dual-pass filter. The cut-off frequency for filtering the kinematic data was set at 8 Hz. For reference, full hip extension and knee extension were set equal to 180° whereas the ankle in neutral position was equal to 0° (- indicated dorsiflexion and angles < 0° indicated plantarflexion) (Lees, Barton & Robinson, 2010).. The take-off velocity (Vto) was calculated from the values of its vertical components.

Electromyography (EMG)

Two bipolar silver chloride surface electrodes (Motion control, IOMED, Inc., voltage range: +4 to +12 V) with 2 cm interface distance were placed on the muscle bellies of MGAS and tibialis anterior (TA) during jumping tests. The EMG signals were amplified with a bandwidth frequency ranging from 1.5 to 2 kHz (common-mode rejection ratio = 90 IB; Z input = 1 LX; Gain = 1,000), filtered (cut off 10–500 Hz) and digitally sampled at a frequency of 1.000 Hz (full-wave rectification, 4th-order, zerolag Butterworth filter).

The mean EMG of the jumps was calculated by full-wave rectification and averaged over eccentric and concentric phases. For CMJ, the movement was divided into eccentric and concentric phases by using the changes in angular position of the knee due to the kinematics. The mean value of MGAS EMG over the eccentric and concentric phase of the jumps was normalized with the EMGmean during the propulsion phase of SJ. Antagonist co-activation was expressed as the ratio of maximum EMG activity of TA to the maximum EMG value of MGAS during the same phase of the jump (Kubo et al., 2007) and referred to as the co-activation index (CI).

Statistical analysis

The effect of the three types of plyometric training on primary variables was analyzed using analysis of variance (ANOVA) with repeated measurements on time (pre and post). Significant Time x Group interactions were further analyzed using pre-post training differences (Tukey test). The level of significance was set at $p<0.05$ for all tests.

Results

Squat Jump

The ANOVA results indicated non-significant interaction effects on maximum vertical ground reaction forces ($F_{2,29} = 0.357$, $p > 0.05$; as described in Table 1), the RFD ($F_{2,29} = 0.557$ $p > 0.05$; Table 1), the Vto ($F_{2,29} = 1.834$, $p > 0.05$; Table 1), and the displacement and velocities of the lower limb joints ($p > 0.05$; as described in Table 1) for all groups. The EMG activity of TA and MGAS during SJ was not significantly ($p > 0.05$) altered by training. Similarly, the ANOVA results indicated a non-significant Time X Group interaction effect on CI ($F_{2,29} = 1.035$, $p > 0.05$).

Countermovement Jump

The ANOVA indicated a significant Time X Group interaction effect on GRFs ($F_{2,29} =8.546$, $p < 0.05$; Table 1). Post-hoc Tukey analysis showed that the Fz max during CMJ significantly increased only for the IH group after training.A significant interaction effect on RFD ($F_{2,29}=144.44$, $p < 0.01$; as described in Table 1) was also observed. Post-hoc analysis showed that all groups improved RFD after training. In contrast, a non-significant interaction effect on Vto and the examined kinematic parameters ($p > 0.05$; as described in Table 1) was found. The EMG results are presented in Figures 3 and 4. The ANOVA results indicated a significant Time X Group interaction effect on normalized EMGmean of MGAS in eccentric phase ($F_{2,29} = 7.058$, $p < 0.05$) and on CI ($F_{2,29} = 10.067$, $p < 0.05$). Post-hoc analysis showed that the activity of MGAS was significantly increased only for the EMS group. Post-hoc showed that the CI increased for the EMS and PH groups. In contrast, a non-significant interaction effect on normalized EMGmean of TA in eccentric phase ($F_{2,29} =2.087$, $p > 0.05$) was observed.

For the concentric phase, the ANOVA indicated a significant Time X Group interaction effect on CI ($F_{2,29} =5.208$ $p < 0.05$). Post-hoc analysis revealed that CI significantly increased for the EMS and PH groups after training. In contrast, a non-significant interaction effect on normalized EMGmean of TA ($F_{2,29} =2.405$, $p > 0.05$) and MGAS ($F_{2,29} = 2.515$, $p > 0.05$) was found.

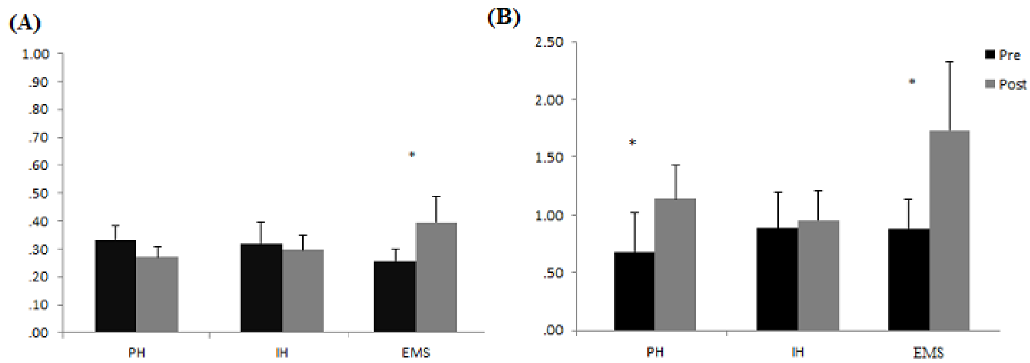

Figure 2. (A) Normalized electromyographic activity during eccentric phase of CMJ for the three training groups of MGAS before (Pre) and after (Post) training period, (B) Co.-activation index for the three training groups before (Pre) and after (Post) training period (* significantly different compared with Pre values ($p < 0.05$).

Table 1. Mean ± SD values of maximal vertical force (Fzmax), rate of force development (RFD), take off velocity (Vto), maximum joint's angles and joint's velocities for each jumping condition before (Pre) and after (Post) training.

	Incline Hopping		Plane Hopping		Electromyostimulation	
	Pre	Post	Pre	Post	Pre	Post
SJ						
Fz_{max}(N)	751.34 ± 189.3	804.12 ± 168.7	946.53 ± 55.8	847.52 ± 83.3	886.81 ± 271.5	841.20 ± 195.0
RFD $(N \cdot sec^{-1})$	362.12 ± 165.1	469.50 ± 120.1	567.25 ± 116.5	480.25 ± 121.8	562.20 ± 138.9	685.20 ± 123.6
$V_{to}(m \cdot sec^{-1})$	2.62 ± 0.40	2.69 ± 0.33	2.64 ± 0.44	2.70 ± 0.50	2.63 ± 0.21	2.68 ± 0.48
Ankle (°)	59.18 ± 15.34	65.45 ± 6.10	54.97 ± 10.89	55.02 ± 7.73	55.38 ± 5.86	60.10 ± 7.54
Knee (°)	178.18 ± 2.82	178.94 ± 1.18	178.80 ± 1.70	179.48 ± 0.60	178.84 ± 1.84	179.24 ± 0.50
Hip (°)	178.36 ± 2.05	179.22 ± 0.87	178.50 ± 1.55	179.39 ± 0.56	177.90 ± 1.37	178.69 ± 1.55
Ankle $(° \cdot sec^{-1})$	711.79 ± 118.85	705.42 ± 147.93	662.70 ± 81.91	679.95 ± 80.97	699.48 ± 122.49	745.43 ± 116.76
Knee $(° \cdot sec^{-1})$	625.23 ± 56.66	648.51 ± 107.95	652.50 ± 28.70	669.24 ± 100.07	661.91 ± 61.19	669.18 ± 82.53
Hip $(° \cdot sec^{-1})$	532.30 ± 97.28	528.64 ± 104.04	554.44 ± 91.42	560.10 ± 120.60	525.46 ± 102.69	561.05 ± 109.04
CMJ						
Fz_{max}(N)	796.75 ± 149.85	1084.62 ± 117.79 †	962.50 ± 55.22	1021.50 ± 51.17	916.66 ± 166.71	1107.66 ± 31.46
RFD $(N \cdot sec^{-1})$	428 ± 90.96	841.37 ± 156.05 †	394.25 ± 114.94	879.75 ± 156.97 †	480.66 ± 32.62	1030 ± 100 †
$V_{to}(m \cdot sec^{-1})$	2.85 ± 0.21	2.98 ± 0.21	2.87 ± 0.75	2.96 ± 0.32	2.88 ± 0.25	2.89 ± 0.40
Ankle (°)	64.16 ± 6.90	65.77 ± 5.45	60.79 ± 3.97	60.34 ± 4.46	58.67 ± 9.36	63.46 ± 6.99
Knee (°)	179.07 ± 1.06	179.19 ± 0.73	179.24 ± 0.54	179.40 ± 0.49	178.92 ± 0.96	179.13 ± 0.70
Hip (°)	179.45 ± 0.60	179.42 ± 0.33	179.28 ± 0.55	179.46 ± 0.52	179.36 ± 0.64	178.92 ± 0.70
Ankle $(° \cdot sec^{-1})$	636.18 ± 112.73	611.66 ± 114.18	602.66 ± 151.36	627.60 ± 119.37	683.03 ± 93.92	702.38 ± 109.05
Knee $(° \cdot sec^{-1})$	570.63 ± 103.21	615.19 ± 71.39	539.58 ± 80.59	565.20 ± 67.87	605.99 ± 80.59	624.21 ± 84.55
Hip $(° \cdot sec^{-1})$	491.86 ± 89.22	524.48 ± 101.64	422.09 ± 89.62	494.82 ± 53.98	497.46 ± 28.74	521.83 ± 40.94

† Significantly different compared with Pre values ($p < 0.05$).

Discussion

The major finding of this study was that neither modified plyometric training nor EMS altered the kinematics characteristic of squat and countermovement jump. Furthermore, the present study indicated that none of the training protocols increased take-off velocity during the jumping tests.

Plane hopping

The results of the present study showed non-significant differences in SJ Vto adaptations between the three groups (Table 1). Although the importance of the tricep surae properties in squat jumping has been previously well described (Bobbert, 2001), the present training protocols did not affect squat jumping performance. Similarly, most of the classical plyometric protocols on a plane ground, which showed positive effects on squat jumps performance, consisted of a combination of plyometric exercises, such as hopping, single leg hops, and hurdle jumps (Arabatzi et al., 2010; Kyrolainen et al., 2004). These increases might be a result of this variance. In contrast, training protocols consisting of hopping exercises fail to affect the static vertical jumping height (Kannas et al., 2012) supporting the idea that hopping on a plane ground does not provide sufficient stimulus to increase vertical jumping performance. The present electromyographic data support this suggestion since there were non-significant changes in electromyographic activity of both medial gastrocnemius and tibialis anterior during squat jumping. These results are similar to previous studies which showed that plyometric training did not change the activity of knee extensors and flexors (Chimera, Swanik, Swanik & Straub, 2004; Kyrolainen et al., 2005) or ankle flexors (Kubo et al., 2007). Moreover, the results of electromyographic activity were accompanied by no changes in sagittal kinematics. In contrast, previous reports indicate that knee joint kinematics might alter after a longer period of plyometric training (Arabatzi et al., 2010; Chappell & Limpisvasti, 2008). The short duration of the training period, the different training protocols, and the ankle specificity of the used exercise could explain these differences.

The present plyometric protocol on a plane ground failed to show any significant effect on countermovement jumping performance. These results are in line with a previous report (Young, Wilson & Byrne, 1999) which showed that a 6-week plyometric training program did not change jumping performance. Moreover, a previous study (Kannas et al., 2012), with a similar experimental approach, showed that both incline and plane hopping did not alter countermovement jump performance. The lack of positive effect of the present plyometric on a plane ground could be partly explained by the lack of specificity principle (Blazevich & Jenkins, 1998; Duchateau & Hainaut, 1984). Plane hopping on countermovement jump performance might occur because hopping involves specifically a fast stretch-shortening cycle for plantar flexors, while countermovement depends mostly on the knee extensors' properties. The ankle co-activation index was increased after plane plyometric training, indicating that the antagonist activity was also increased. Previous studies supported that plyometric training affects muscle co-activation, without any significant effect on final performance (Chimera et al., 2004; Kubo et al., 2007). This hypothesis was also confirmed by the absence of any alteration in joint displacement and angular velocities. A previous study (Lamas et al., 2012) supported that even if countermovement jump performance was increased after plyometric training, it might not affect the timing and the maximal displacement of the joints.

Incline hopping

For the incline hopping group, the Vto during squat jump did not increase. Our results are in agreement with Holcomb, Lander, Rutland and Wilsons' (1996) study which used a modified plyometric protocol for different joints. They found that despite the significant changes in joints' angles the final vertical performance did not alter. The factor which might explain the variance of these results is the exercises that were used. Modified drop jumps might provide a better stimulus compared with hopping. Furthermore, a previous report (Markovic & Mikulic, 2010) suggested that plyometric training might be more effective in improving vertical jumping which includes a fast stretch-shortening cycle.

Similar results were found for the countermovement jump after incline hopping training. The present results showed that hopping on incline ground did not affect jumping Vto of countermovement jump. These results were accompanied by the absence of alterations in muscle activity and joint participation. This is in contrast with Holcomb et al. (1996), who indicated that modified drop jumps affected joints' participation without any changes in the final performance. McErlain-Naylor, King and Pain (2014) indicated that countermovement technique is a significant factor, which affects final jumping performance. Our results showed that both muscle activity and jumping technique did not change after four weeks of training consisting of incline hopping. A previous study (Kannas et al., 2012) regarding the effects of incline plyometrics suggested that the increased compliance of aponeurosis might be responsible for the increased performance. In fact, previous studies (Chimera et al., 2004; Lichtwark & Wilson, 2007) suggested that ankle kinematics are similar in persons with different levels of compliance. This could also be a possible explanation for the lack of biomechanical alterations in the jumping technique. On the other hand, Fz and RFD were both increased and improved after incline training suggesting that any changes probably were caused by adaptations of muscle force capacity.

EMS

Electromyostimulation training of the plantar flexors did not affect squat jumping performance. Maffiuletti et al. (2002) and Malatesta et al. (2003) showed small increases in squat jump height after six weeks of training or even a decrease in squat jumping performance after three weeks of training (Brocherie, Babault, Cometti, Maffiuletti & Chatard, 2005). Although there were used similar stimulation parameters to the ones employed in other successful trials (Filipovic et al., 2012), the results of the present study suggest that a short term of EMS training did not affect squat jumping performance. Babault et al. (2007) showed that EMS training could affect positive squat jumping in professional subjects. However, in the present study, all the participants were untrained subjects. It is possible that EMS training might overload the neuromuscular system of untrained participants, leading to small decreases in squat jump performance immediately after the training period (Filipovic et al., 2012). Furthermore, the activity of plantar and dorsi flexors, during the squat jump, did not alter after the training period. It is possible that isometric type of training, such as EMS, does not affect muscle co-activation and jumping technique during concentric jumps.

The jumping Vto of countermovement did not change after EMS training. This is in agreement with previous reports (Brocherie et al., 2005), which reported that isometric local EMS training might not affect the performance of a multi-joint movement such as jumping. Most of the previous studies regarding EMS adaptations suggested that EMS training should be followed by plyometric training to transfer any gain in multi-joint movement. Furthermore, a previous study (Maffiuletti et al., 2002) showed that plantar flexors activity increases after EMS training. However, it is not clear whether this adaptation also occurs in multi-joint movements such as jumping. The present results showed increased activity of medial gastrocnemius and co-activation index during the eccentric phase of the countermovement jump. These results could be explained by the preferential activation of large motor units of the fiber II caused by the EMS (Brocherie et al., 2005; Maffiuletti et al., 2002). This different recruitment could explain the increased muscle activity during the eccentric phase and the improved RFD. EMS training was not found to alter biomechanical parameters of a countermovement jump. Similarly, Malatesta et al. (2003) and Maffiuletti et al. (2002) proposed that any possible positive effects of EMS on untrained participants could not acute transfer in jumping. The untrained participants, compared with trained and elite athletes, show less intra-muscular and inter-muscular coordination ability, which in turn makes it difficult to transfer the gained strength into the countermovement jump. Thus, EMS should be followed or combined with plyometric training to enable the central neural system to adapt to an optimal jumping technique.

Conclusion

In conclusion, the present findings suggest that ankle-specific training for a short period (4 weeks) caused no significant changes in the vertical jumping performance during SJ. For the three different training protocols, both muscle activity of the ankle joint and the lower limb biomechanics did not change after the intervention period. These results might reflect the small participation of MGAS during a concentric jump such as SJ. Our findings for the CMJ showed that none of the intervention protocols significantly change the final performance. In contrast, IP increased the vertical force during the CMJ. This increment was accompanied by increased muscle activation of MGAS during the eccentric phase as well as increased RFD. On the contrary, both EMS and PP showed increases in both in RFD and the activity of TA due to greater CI. Similar to SJ, the biomechanical parameters of squat and countermovement jump did not alter after four weeks of ankle-specific training. The duration of the training protocol might be too short to cause any changes. A longer training period might lead to significant changes in jumping techniques.

References

Arabatzi, F., Kellis, E., & Saez-Saez De Villarreal, E. (2010). Vertical jump biomechanics after plyometric, weight lifting, and combined (weight lifting + plyometric) training. *Journal of Strength and Conditioning Research, 24*, 2440-2448.

Arabatzi, F., Patikas, D., Zafeiridis, A., Giavroudis, K., Kannas, T., Gourgoulis, V., & Kotzamanidis, C.M. (2014). The post-activation potentiation effect on squat jump performance: age and sex effect. *Pediatric Exercise Sciences, 26*, 187-194.

Azreh, R., Hashemi Oskouei, A., & Emamian Shirazi, S. A. (2020). Effects of Short-term Plyometric Training on Countermovement Vertical Jump Height and Kinematics of Take-Off. *Thrita*, *9*(2). https://doi.org/10.5812/thrita.108054

Babault, N., Cometti, G., Bernardin, M., Pousson, M., & Chatard, J. C. (2007). Effects of electromyostimulation training on muscle strength and power of elite rugby players. *Journal of Strength and Conditioning Research, 21*, 431-437.

Blazevich, A. J., & Jenkins, D. (1998). Physical performance differences between weight-trained sprinters and weight trainers. *Journal of Science and Medicine in Sport, 1*, 12-21.

Bobbert, M. F. (2001). Dependence of human squat jump performance on the series elastic compliance of the triceps surae: a simulation study. *Journal of Experimental Biology, 204*, 533-542.

Brocherie, F., Babault, N., Cometti, G., Maffiuletti, N., & Chatard, J. C. (2005). Electrostimulation training effects on the physical performance of ice hockey players. *Medicine and Science in Sports and Exercise, 37*, 455-460.

Chappell, J. D., & Limpisvasti, O. (2008). Effect of a neuromuscular training program on the kinetics and kinematics of jumping tasks. *American Journal of Sports Medicine, 36*, 1081-1086.

Chimera, N. J., Swanik, K. A., Swanik, C. B., & Straub, S. J. (2004). Effects of plyometric training on muscle-activation strategies and performance in female athletes. *Journal of Athletic Training, 39*, 24-31.

Duchateau, J., & Hainaut, K. (1984). Isometric or dynamic training: differential effects on mechanical properties of a human muscle. *Journal of Applied Physiology: Respiratory, Environmental and Exercise Physiology, 56*, 296-301.

Filipovic, A., Kleinoder, H., Dormann, U., & Mester, J. (2012). Electromyostimulation-a systematic review of the effects of different electromyostimulation methods on selected strength parameters in trained and elite athletes. *Journal of Strength and Conditioning Research, 26*, 2600-2614.

Holcomb, W. R., Lander, J. E., Rutland, R. M., & Wilson, G. D. (1996). The effectiveness of a modified plyometric program on power and the vertical jump. Journal of Strength and Conditioning Research, 10, 83-88.

Kannas, T. M., Kellis, E., & Amiridis, I. G. (2012). Incline plyometrics-induced improvement of jumping performance. *European Journal of Applied Physiology, 112*, 2353-2361.

King, J. A., & Cipriani, D. J. (2010). Comparing preseason frontal and sagittal plane plyometric programs on vertical jump height in high-school basketball players. *Journal of Strength and Conditioning Research, 24*, 2109-2114.

Kubo, K., Morimoto, M., Komuro, T., Yata, H., Tsunoda, N., Kanehisa, H., & Fukunaga, T. (2007). Effects of plyometric and weight training on muscle-tendon complex and jump performance. *Medicine and Science in Sports and Exercise, 39*, 1801-1810.

Kyrolainen, H., Avela, J., McBride, J. M., Koskinen, S., Andersen, J. L., Sipila, S., & Komi, P. V. (2004). Effects of power training on mechanical efficiency in jumping. *European Journal of Applied Physiology, 91*, 155-159.

Kyrolainen, H., Avela, J., McBride, J. M., Koskinen, S., Andersen, J. L., Sipila, S., & Komi, P. V. (2005). Effects of power training on muscle structure and neuromuscular performance. *Scandinavian Journal of Medicine and Science in Sports, 15*, 58-64.

Lamas, L., Ugrinowitsch, C., Rodacki, A., Pereira, G., Mattos, E. C., Kohn, A. F., & Tricoli, V. (2012). Effects of strength and power training on neuromuscular adaptations and jumping movement pattern and performance. *Journal of Strength and Conditioning Research, 26*, 3335-3344.

Lees, A., Barton, G., & Robinson, M. (2010). The influence of Cardan rotation sequence on angular orientation data for the lower limb in the soccer kick. *Journal of Sports Sciences*, *28*, 445-450.

Lichtwark, G. A., & Wilson, A. M. (2007). Is Achilles tendon compliance optimised for maximum muscle efficiency during locomotion? *Journal of Biomechanics, 40*, 1768-1775.

Maffiuletti, N. A., Cometti, G., Amiridis, I. G., Martin, A., Pousson, M., & Chatard, J. C. (2000). The effects of electromyostimulation training and basketball practice on muscle strength and jumping ability. *International Journal of Sports Medicine, 21*, 437-443.

Maffiuletti, N. A., Pensini, M., & Martin, A. (2002). Activation of human plantar flexor muscles increases after electromyostimulation training. *Journal of Applied Physiology, 92*, 1383-1392.

Malatesta, D., Cattaneo, F., Dugnani, S., & Maffiuletti, N. A. (2003). Effects of electromyostimulation training and volleyball practice on jumping ability. *Journal of Strength and Conditioning Research, 17*, 573-579.

Markovic, G., & Mikulic, P. (2010). Neuro-musculoskeletal and performance adaptations to lower-extremity plyometric training. *Sports Medicine, 40*, 859-895.

McErlain-Naylor, S., King, M., & Pain, M. T. (2014). Determinants of countermovement jump performance: a kinetic and kinematic analysis. *Journal of Sports Sciences, 32*, 1805-1812.

Pano-rodriguez, A., Beltran-garrido, J. V., & Hernández-gonzález, V. (2019). Effects of whole-body electromyostimulation on health and performance : a systematic review. *BMC Complementary and Alternative Medicine, 19,* 1–14.

Toumi, H., Best, T. M., Martin, A., & Poumarat, G. (2004). Muscle plasticity after weight and combined (weight + jump) training. *Medicine and Science in Sports Exercise, 36*, 1580-1588.

Young, W. B., Wilson, G. J., & Byrne, C. (1999). A comparison of drop jump training methods: effects on leg extensor strength qualities and jumping performance. *International Journal of Sports Medicine, 20*, 295-303.

Wirtz, N., Dörmann, U., Micke, F., Filipovic, A., Kleinöder, H., & Donath, L. (2019). Effects of Whole-Body Electromyostimulation on Strength-, Sprint-, and Jump Performance in Moderately Trained Young Adults: A Mini-Meta-Analysis of Five Homogenous RCTs of Our Work Group. *Frontiers in Physiology*, *10* (November). https://doi.org/10.3389/fphys.2019.01336