The Effects of Electromyostimulation Training and Basketball Practice on Muscle Strength and Jumping Ability

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The aim of this study was to investigate the influence of a 4-week electromyostimulation training program on the strength of the knee extensors and the vertical jump performance of 10 basketball players. Electromyostimulation sessions were carried out 3 times weekly; each session consisted of 48 contractions. Testing was carried out before and after the electromyostimulation training program (week 4) and once more after 4 weeks of normal basketball training (week 8). At week 4, isokinetic strength increased significantly ($p < 0.05$) at eccentric and high concentric velocities (between 180 and $360^\circ \times s^{-1}$); this was not the case for low concentric velocities (60 and $120^\circ \times s^{-1}$). Electromyostimulation training increased also isometric strength at the two angles adjacent to the training angle ($p < 0.01$). Squat jump increased significantly by 14% at week 4 ($p < 0.01$), whereas counter movement jump showed no change. At week 8, gains in isokinetic, isometric strength and squat jump performance were maintained and the counter movement jump performance increased significantly by 17% ($p < 0.01$). Electromyostimulation as part of a short strength-training program enhanced knee extensor strength and squat jump performance of basketball players.

Key words: Isokinetic dynamometer, isometric strength, knee extensors, strength training, squat jump, counter movement jump.

Introduction

Electromyostimulation (EMS) is mainly used in rehabilitation programs when nervous function has been compromised, for example, as a result of injury. It is considered to be a good complement or supplement to the voluntary process [14]. In recent years, it has also been used by athletes in the context of training programs to develop strength and physical performance. Efficacy studies have been carried out in cycling [46], swimming [37], and weightlifting [12]. However, none were performed in team sport like basketball. The quadriceps [35,40], triceps surae [30], latissimus dorsi [37], and biceps brachii [7] muscles have previously been electrostimulated. Widely differing gains in strength have been reported, for example from 0% to 44% [10,28,40,43]. Differing stimulation methods, training and testing protocols, pre-training status, and inter-individual variation may account for some of the discrepancies.

Only one study has examined whether EMS training has an effect on vertical jump performance [49]. These authors reported that a specific resistive exercise program with EMS improved vertical jump height in a group of professional tennis instructors and recreational sportsmen.

A typical basketball match involves a mean total of 46 ± 12 jumps for each player [31], with or without a stretch-shortening cycle (SSC). Hubley and Wells [25] have shown that quadriceps femoris activation contributes 50% of the work involved in a vertical jump. Similar findings have been reported by Bosco et al. [5] for the squat (SJ) and counter movement jumps (CMJ), even though the muscular activation involved is different. Indeed during CMJ more work is done during the concentric phase. The SSC allows elastic energy to be stored and then re-used, something which cannot happen during SJ. A study [22] performed on male and female basketball players has shown that SJ and CMJ performances correlated significantly with the maximal leg extension isometric force. Thus, the role of maximal strength may also be important for explosive strength development. Although explosive force production of the leg extensor muscles has been shown to be an important neuromuscular performance characteristic among basketball players [18], very few studies have been conducted to determine the most effective training program for the improvement of muscular strength and vertical jump ability over a competitive basketball season [1,23]. Amiridis et al. [1] have also observed that regular basketball practice had no beneficial effect on strength performance.

Therefore, the main aim of this study was to determine whether or not a 4-week electromyostimulation training program,

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added to a standardized basketball training, could affect quadriceps strength and vertical jump performance in a group of 20 basketball players. A secondary purpose was to determine whether the effects of training could be either maintained or increased by a further 4-week period of standardized basketball training.

Material and Methods

Subjects

Twenty male basketball players competing in division 2 of the French Basketball Federation League took part in this study (age 24.7 ± 3.9 years; height 193.9 ± 6.9 cm; mass 87.7 ± 8.9 kg). They were randomly assigned to an electrostimulated (ES, $n = 10$) or control group (C, $n = 10$). All 20 players had trained and competed regularly in basketball for on average 6 – 10 years. None of them had previously engaged in systematic strength training or electromyostimulation experience. The subjects, all free from previous knee injury, agreed to participate in the study on a voluntary basis and signed an informed consent form. Approval for the project was obtained from the University Committee on Human Research.

EMS training

One week before the beginning of the stimulation period, the ES group participated in two practice sessions to acquaint themselves with stimulation parameters. Table **1** shows the 4-week EMS training program. It consisted of twelve 16-minute sessions, with 3 sessions per week. During the stimulation, subjects were seated on a machine used for strength training of the quadriceps (Multi-Form’, La Roque D’Anthéron, France) with the knee joint fixed at a 60° angle (0° corresponding to the full extension of the leg). Both vastus medialis (VM) and vastus lateralis (VL) muscles could be stimulated simultaneously. A portable battery-powered stimulator (Compex-2, Medicompex SA, Ecublens, Switzerland) was used. Three 2 mm-thick, self-adhesive electrodes were placed over each thigh. The positive electrodes, measuring $25\ cm^2$ ($5\ cm \times 5\ cm$), which had membrane depolarizing properties, were placed as close as possible to the motor point of the VM and VL muscles and near the proximal insertion of each muscle. The negative electrode, measuring $50\ cm^2$ ($10\ cm \times 5\ cm$), was placed over the femoral triangle, 1 – 3 cm below the inguinal ligament. Rectangular-wave pulsed currents (100 Hz) lasting 400 µs were used. Each 3 second contraction was followed by a pause lasting 17 seconds. During the training sessions each muscle performed 48 contractions. Intensity (range 0 – 100 mA) was monitored on-line and determined by the subject at the start of each EMS session to produce a force of 80 % of their pre-test maximal voluntary contraction (MVC) score. This level has to be reached at the beginning of the stimulation and maintained for 3 s. In each case, the level of force was measured with a myostatic type dynamometer (Allegro, Sallanches, France) and verified by the examiner. The maximally tolerated intensity varied between 60 and 100 mA depending on differences among subjects in pain threshold. No subject reported serious discomfort from this current. The ES group preceded each MVC measure and each EMS session with ten submaximal voluntary muscle contraction (from 30 % to 80 % of the MVC).

Table 1 Weekly training protocol

	Mon	Tue	Wed	Thu	Fri	Sat	Sun
11.30 – 12 a.m.	EMS	EMS		EMS			REST
7.30 – 9 p.m.	BB	BB	BB	BB	BB	GAME	

EMS: electromyostimulation session
BB: standardized basketball session

Standardized basketball training

During the experiment, the athletes all took part in basketball sessions, which were supervised by the same coach (5 sessions per week; 90 ± 5 min per session; Table **1**). The typical session was divided into warm-up, main, and recovery periods. The warm-up lasted about 25 min and included jogging at increasing velocities, ball handling exercises, jump shots, and 10 min of static stretching. The main part of the sessions involved a variety of skills with different objectives (defensive fundamentales, attacking fundamentales, collective defence, attacking against different defences, special situations). The work/rest ratio was close to 1. The recovery period lasted about 20 min and included jogging at low velocity and static stretching for 10 min.

Strength testing

One week before testing the subjects from both groups were familiarized with an isokinetic dynamometer (Biodex Corporation, Shirley NY, USA) during one session of the complete experimental procedure. The day of the test subjects warmed up by performing five submaximal concentric actions at each experimental angular velocity. The strength measurements involved 3 maximum extensions of the right leg, from 90° of flexion to full extension (0°), performed at 8 angular velocities (concentric: $60^\circ \times s^{-1}$, $120^\circ \times s^{-1}$, $180^\circ \times s^{-1}$, $240^\circ \times s^{-1}$, $300^\circ \times s^{-1}$, $360^\circ \times s^{-1}$, and eccentric: $60^\circ \times s^{-1}$ and $120^\circ \times s^{-1}$) and by 5 isometric contractions at 45°, 55°, 65°, 75°, and 85°. Constant Angle Torques at 65° were computed directly by the Biodex software and included in the Torque/Angular Velocity relationship. A 4 min rest period was allowed between trials to eliminate the effects of fatigue. For the isometric action, the effort lasted 3 s with a 2 min rest period between successive efforts. Isokinetic and isometric trials were randomly presented, and only the best performances were included in the analysis. To minimize hip and thigh motion during the contractions, straps were applied across the chest, pelvis, mid-thigh, and lower leg. A strap also secured the leg to the Biodex lever arm, and the alignment between the centre of rotation of the dynamometer shaft and the axis of the knee joint was checked at the beginning of each trial. The arms were positioned across the chest with each hand clasping the opposite shoulder. Torques were gravity corrected at each joint angle, using the maximum torque of the weight of the limb obtained at the joint angle where the gravity effect was greatest [44]. For all the subjects, tests were performed before and after training and at the same time of day on each occasion.

Vertical jump testing

Each subject performed vertical jumps on a Bosco's mat (Tel. Si. srl, Vignola, Italy); a digital timer was connected to the system for measuring the flight times of the jumps. Knee joint angle was measured from an electrogoniometer (Tel. Si. srl, Vignola, Italy) fixed on the right leg of the subjects. Calibration of the goniometer was performed prior to each test. The squat jump (SJ) was measured starting from a static semi-squatting position (knee angle 90°) and without any preliminary movement. The counter movement jump (CMJ) was performed starting from a standing position, then squatting down to a knee angle of 90 ± 5° and then extending the knee in one continuous movement. During these tests the arms were kept in the akimbo position to minimize their contribution. The position of the upper body was also standardized so that a minimum of flexion and extension of the trunk occurred. Subjects were asked to jump as high as they could three times, and the best performance was reported.

Statistical analysis

Standard statistical techniques were used to calculate means, standard deviations, standard error of the means, and linear correlation coefficients. Statistical analysis of the data was accomplished with a two-way analysis of variance: group (ES, C) and time (baseline, week 4, week 8) were the independent variables. A one-way ANOVA was performed in the ES group at week 4 in order to compare both absolute and percent increases across joint angles. When significant treatment effects occurred, LSD post hoc tests were used to test significant differences among means. The level of significance was set at $p \leq 0.05$ for all procedures.

Results

Before training there were no significant differences between the ES and C groups in physical characteristics, knee extensor strength, and vertical jump performance.

Effect on strength

In the ES group, the isokinetic strength significantly increased (Fig. **1**) at week 4 under eccentric conditions (+29% at $-120 \times s^{-1}$, $p < 0.05$; +37% at $-60° \times s^{-1}$, $p < 0.01$) and under concentric conditions at high velocities (+43% at $360° \times s^{-1}$, $p < 0.01$; +36%, +30%, and +32% at 300, 240, and $180° \times s^{-1}$, respectively, $p < 0.05$). EMS training did not cause a significant increase of the isokinetic strength at low concentric velocities (+15% at 60 and $120° \times s^{-1}$). Post hoc analysis indicated that isometric strength increased significantly only at the two angles adjacent to the training angle (Fig. **2**), i.e. 55° ($p < 0.01$) and 65° ($p < 0.01$). However, ANOVA on the absolute and percent increases showed no difference across joint angles. In group C, no change in isokinetic or isometric strength was observed after the first 4-week period. At week 8, strength values remained similar to those observed at week 4, for both groups. For the whole group of subjects no significant correlation coefficients were found between the strength measurements and the vertical jump performances before or after training. However, after 4 weeks of EMS training variations in isometric strength measured at 65° and the variations of the SJ performances were significantly related ($r = 0.65$, $p < 0.05$) for the ES group (Fig. **3**).

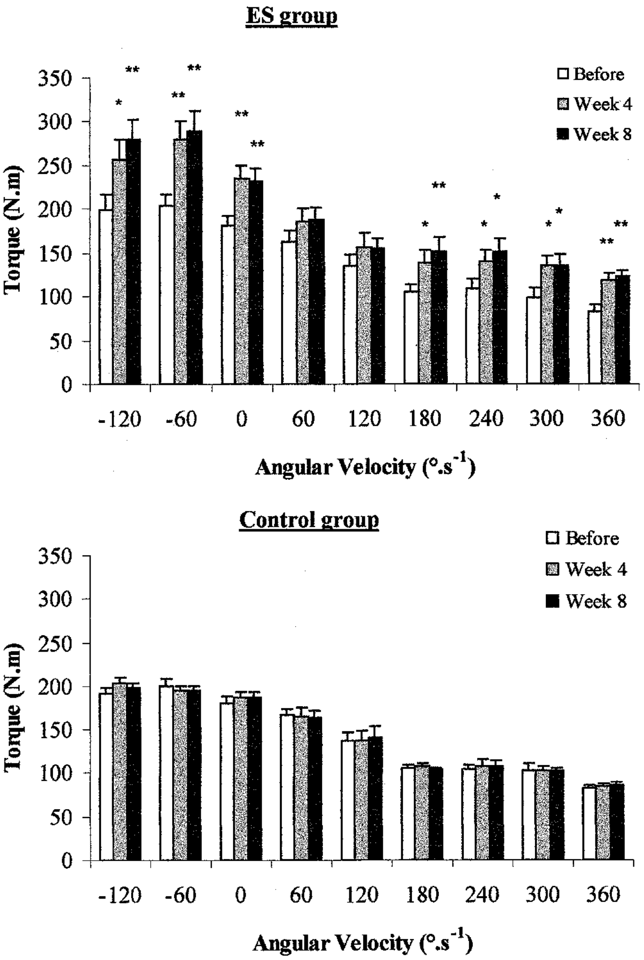

Fig. 1 Torque/Angular Velocity relationship of knee extensors using Constant Angular Torque (65°) on Electrostimulated (upper graph) and Control group (lower graph). Values are means ± SE. In ES group, * and ** indicate that values at week 4 and/or at week 8 were significantly higher than pre-training values at the $p < 0.05$ and $p < 0.01$ levels, respectively.

Effect on vertical jump performance

In the ES group, SJ performance increased significantly ($p < 0.01$) by 14% after the 4-week EMS training program, whereas CMJ remained unchanged (Table **2**). In the C group, no change in vertical jump performance was observed at week 4.

SJ performance at week 8 was not significantly different from that at week 4 for either group. In contrast, in the ES group, CMJ performance increased significantly ($p < 0.01$) by 17% (Table **2**) at week 8. No significant differences were observed for group C.

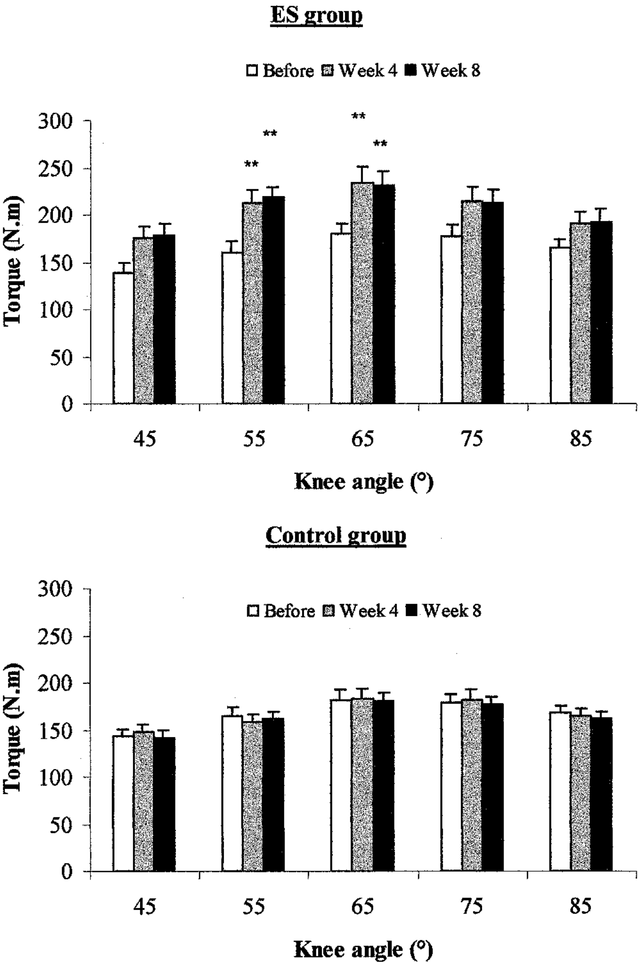

Fig. 2 Torque/Angle relationship of knee extensors on Electrostimulated (upper graph) and Control group (lower graph). Values are means ± SE. In ES group, ** indicate that the values at week 4 and/or at week 8 were significantly higher than pre-training values ($p < 0.01$).

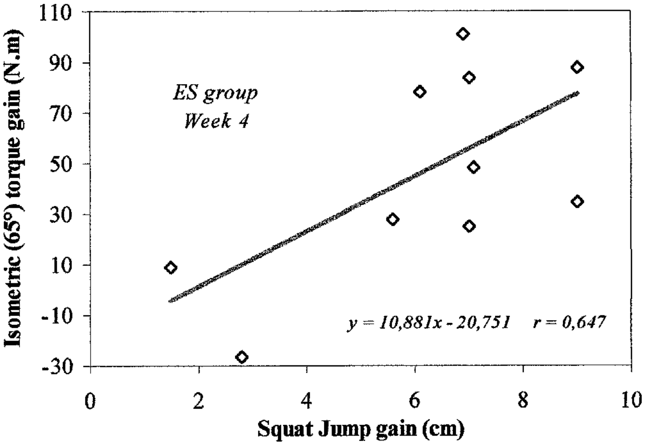

Fig. 3 Relationship between the variations in SJ performance and the gain in isometric torque (at 65°) at week 4, for the ES group ($p < 0.05$).

Table 2 Squat jump and counter movement jump performances (Mean values ± SD) for the electrostimulated and control group

		ES	Control
SJ (cm)	Before	44.8 ± 1.0	44.1 ± 1.8
	Week 4	51.0 ± 1.3**	46.1 ± 1.8
	Week 8	53.0 ± 2.0**	44.9 ± 0.9
CMJ (cm)	Before	53.0 ± 1.3	51.0 ± 1.3
	Week 4	52.8 ± 1.1	52.5 ± 1.6
	Week 8	62.2 ± 1.2**	51.9 ± 1.1

** indicate significant difference from values before training ($p < 0.01$)

Discussion

The main findings of the study indicated that a 4-week electromyostimulation training program in addition to a standardized basketball training: 1) increased strength of the knee extensors under eccentric, concentric, and isometric conditions; 2) the isokinetic strength increased significantly under eccentric and concentric conditions at high velocities but not under concentric conditions at low velocities; 3) the isometric strength increased significantly only at the two angles adjacent to the training angle; 4) the squat jump performance increased by 14%.

The data also indicated that following a 4-week EMS training program, 4 weeks of standardized basketball training: 1) maintained the gain in isokinetic, isometric strength and SJ performance produced by the electromyostimulation training program; 2) enhanced CMJ performance by 17%.

Effects of the EMS training program

This program led to improvement of eccentric, concentric, isometric, and SJ performances. It suggests that EMS may be a useful way of developing muscular strength and vertical jumping ability without SSC in a group of basketball players. These findings are consistent with previous reports confirming that brief periods of electromyostimulation have beneficial effects on muscle strength [30,37].

It is now generally accepted that neural adaptations predominate in short-term strength training [39] and EMS training [7,14,30]. In our study, after EMS training program isokinetic strength increased significantly under eccentric and high concentric velocities, whereas no significant difference was observed at low concentric velocities. This could partly be accounted for by preferential neural adaptation of the fast twitch units induced by electrical stimulation. Indeed, type IIb fibers are preferentially recruited during eccentric contractions [15,34] and increasingly recruited at high concentric velocities [9,16,47]. Moreover, during EMS motor units are activated in an order different to those predicted by Henneman's size principle [24]. During voluntary actions, the smallest motoneurons (supplying type I fibres) are activated first [33], whereas during electromyostimulation the largest motoneurons (innervating type II fibres) are activated first and to a greater extent [14]. The order of motor unit activation during EMS has been shown to depend on at least three factors. The first is the diameter of the motor axon. In voluntary actions, the motor units are activated by the synaptic current invading the motoneuron. As a consequence, the slow motor units (high input resistance), which need only a small depolarizing current, are activated more easily than larger motor units (low input resistance). In contrast, during electrical stimulation the current is applied extracellularly to the nerve endings, and large motoneurons, which have a low threshold of excitability, are activated more rapidly [21,42]. The second factor is the distance between the axon and the active electrode. As confirmed by Lexell et al. [29], the largest motor units are often located on the muscle surface, and the distance between the motor units and the electrode is small. A third possible factor could be the activation of sensory receptors and cutaneous afferent impulses. Their input during EMS could change the order of recruitment [17,26]. To determine which parameters of electrical stimulation produce the best results, it is important to know the maximum level of evoked force that the subject is capable of actively producing. From previous studies [11,30,32,37] it appears that the maximum force is elicited at frequencies between 80 – 100 Hz, delivered as short pulses to reduce pain and unpleasant sensations [41].

Under isometric conditions, although absolute and percent increases were not significantly different across joint angles, post hoc analysis on maximal torques showed significant increases only at 55° and 65°, which indicates a close connection between the training position and the gain in strength. This is in line with previous reports suggesting that the increase in strength after voluntary isometric training [27,45] and EMS training [30,38] is angle specific. This angle specificity of isometric training has been attributed to some form of neural adaptation, with a greater increase in motor unit activation at the trained joint angles [45] and no increase in evoked contraction strength [27]. It has also been suggested that in the quadriceps femoris muscle average firing rates of motor units (rate coding) showed little change until 30% MVC [8]. Above that level of force mean motor unit firing rates progressively increased suggesting a quadratic relationship. In the case of EMS training, neural adaptations could be more likely related to an increased rate coding at the training angle. Even though no EMG or cross-sectional area measurements were performed in our study, we are justified in assuming that EMS training program had produced nervous adaptations rather than muscular hypertrophy. Whatever the underlying mechanism related to strength gain, EMS appears to be an effective stimulus in developing maximal strength.

In basketball a significant increase in the maximal strength may also be important for explosive strength development. This was confirmed by the significant correlation obtained between changes in SJ height and increases in isometric quadriceps strength at a knee angle of 65°, for the ES group. Squat jump performance increased by 14%, showing that the EMS training method can be used to enhance the contractile qualities of muscle under isometric and dynamic conditions [30]. Although Bosco and Komi [41] reported that fast twitch fibers contribute to the performance in squat jump and counter movement jump, in our study we found no correlations between absolute or percent increase in jumping ability and increase in concentric torque at high angular velocity. However, van Ingen Schenau et al. [48] suggested that subjects having a high percentage of slow twitch fibres better benefit from a counter movement. In our opinion, and according to Goubel [19], the influence of fiber type is more complex in functional tasks such as jumping. Recent investigations have reported low correlations between the isokinetic strength measurements and the functional tests [20,36]. Furthermore, some authors have focused on the relationship between open (OKC) and closed kinetic chain (CKC) strength on knee extensor muscles and jumping performance [2,3]. They concluded that CKC muscular strength is more highly related to jumping performance than OKC strength. Augustsson et al. [2] focused on 6-weeks CKC (barbell squat) and OKC (knee extension and hip adduction) training. They showed that the subjects trained by squat exercise improved by 10% vertical jump performance while no changes were seen for the OKC group. In our study, EMS training and strength testing were performed solely in open kinetic chain. This could partially explain the lack of correlations between isokinetic and jumping measurements.

Effects of the standardized basketball training

The 4-week period of standardized basketball training maintained the gain in isokinetic, isometric strength and SJ performance achieved by the EMG training program. The same program was also followed for the 8 weeks by the control group with no gain in strength or vertical jump performance. It can therefore be concluded that standardized basketball training maintained muscle aptitude. However, it is not specific enough to develop muscle strength and vertical jump aptitude, which confirms the findings of Amiridis et al. [1]. Specific training programs such as weight training or EMS training must be recommended to basketball players to develop their strength.

After 4 weeks of electromyostimulation, CMJ performance was not improved, but an improvement was found after 8 weeks. During CMJ, the muscles are first stretched while active. As a result of this muscular lengthening, potential energy is stored in the series elastic component (SEC) and then released during subsequent shortening [5,6]. The present findings suggest that improvements in the strength of muscles involved in performing complex movements using elastic energy, such as CMJ, require a longer period of specific training before beneficial effects are observed in jumping performance. As a general rule, EMS training is not specific to develop elastic behaviour of skeletal muscle. The values for the jumping performance among the present basketball players were much higher than those recorded for Finnish players in the Häkkinen study [22]. The diversity in testing apparatus could partially explain these differences.

In our study, the EMS training was basically a form of isometric strength training. Since there are some practical limitations to subjecting athletes to this type of training, it could be interesting to know if voluntary isometric training would have produced similar results among our subjects. Many investigators have compared submaximal EMS with voluntary contractions of similar intensity and duration in healthy muscles (for a review, see [21]). Indeed, the observed gains in strength induced by isometric EMS training could be as large as but not greater than those induced by voluntary isometric exercise. Therefore, we suggest that the number and the type of trained motor units may be different in these two procedures [13]. However, the relative contribution of the two procedures remains to be confirmed for elite athletes engaged in competitive sport practice.

As a practical recommendation for basketball players it is suggested that EMS training could be used over the season in two ways. Firstly, it enhances strength and vertical jump performance without interfering with basketball training. This suggests that electromyostimulation could find its place early in the season. Secondly, players' abilities can subsequently be maintained at a high level throughout the season by means of basketball training only.

To summarize, this study demonstrated that an increase in the eccentric, isometric, and concentric strength of the knee extensors and vertical jump performance without SSC can be achieved in a relatively short period after a 4-week EMS training program. The gain in knee extensor strength subsequently enhanced CMJ performance, but only after a further 4 weeks of standardized basketball training.

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