RESEARCH NOTE

FEASIBILITY AND EFFICACY OF PROGRESSIVE ELECTROSTIMULATION STRENGTH TRAINING FOR COMPETITIVE TENNIS PLAYERS

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ABSTRACT

Maffiuletti, NA, Bramanti, J, Jubeau, M, Bizzini, M, Deley, G, and Cometti, G. Feasibility and efficacy of progressive electrostimulation strength training for competitive tennis players. *J Strength Cond Res* 23(2): 677–682, 2009—The purpose of this preliminary study was to show the feasibility of electrostimulation (ES) strength exercise incorporated into tennis sessions during the preparatory season of competitive players, and its impact on anaerobic performance. Twelve tennis players (5 men, 7 women) completed 9 sessions of quadriceps ES (duration: 16 minutes; frequency: 85 Hz; on-off ratio: 5.25–25 seconds) during 3 weeks. The ES sessions were integrated into tennis training sessions. Subjects were baseline tested and retested 1 (week 4), 2 (week 5), 3 (week 6), and 4 weeks (week 7) after the ES training program for maximal quadriceps strength, vertical jump height, and shuttle sprint time. Participants were able to progressively increase ES current amplitude and evoked force throughout the 9 training sessions, with an optimal treatment compliance of 100%. Maximal quadriceps strength significantly increased during the entire duration of the experiment ($p < 0.001$). Countermovement jump height at week 5 (+5.3%) and week 6 (+6.4%) was significantly higher than at baseline ($p < 0.05$). In addition, 2 × 10-m sprint time at week 6 was significantly shorter (−3.3%; $p = 0.004$) compared with pretraining. The 3-week ES strength training program was successfully incorporated into preseason tennis training with a linear progression in all training parameters. Throughout the study period, a delayed enhancement of anaerobic power and stretch-shortening cycle performance was observed. Progressive ES strength training may be safely included in the early tennis season and can lead to improvements in the anaerobic performance of men and women players.

KEY WORDS quadriceps, vertical jump, sprint, stretch-shortening cycle

INTRODUCTION

Surface electrostimulation (ES) involves artificially activating the muscle with a protocol designed to minimize the discomfort associated with the stimulation. This method has been used either to supplement or to substitute for voluntary activation of muscle in many rehabilitation settings, for instance, for muscle maintenance during prolonged periods of immobilization (16). Electrostimulation strength training also has proven its feasibility and effectiveness for healthy individuals (6,17) and for highly trained athletes (3,19,20,22), particularly for quadriceps muscle strengthening (2). The rationale for adopting short (3–4 weeks) ES training programs in addition to voluntary exercise in athletes is based primarily on 2 ideas. First, ES imposes a particular pattern of motor unit recruitment–fast motor unit activation at relatively low force levels (9)–which could be viewed as a new form of stress from a neuromuscular and metabolic point of view. Second, ES strength training programs are usually less time consuming than voluntary programs (22); beneficial effects have been observed after 4 weeks of training with only 36 min·wk^{-1} of ES (22).

Several studies with team sport athletes (basketball, volleyball, rugby, ice hockey) have reported significant increases in quadriceps muscle strength and even in anaerobic power production (jump height and sprint time) after multiple sessions of ES (1,3,19,20,22), likely to affect field performance. To our knowledge, the feasibility and efficacy of this artificial training modality have never been explored in athletes competing in individual sports requiring high levels of anaerobic power, and

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particularly in tennis players, who have a limited amount of time for conditioning because of their extremely demanding competitive calendar. In spite of this, international tennis trainers (e.g., Paul Dorochenko) (7) and players (e.g., Roger Federer, Justine Henin-Hardenne) (5,7) claim to have used ES for quadriceps muscle strengthening and as a recovery modality between matches.

The main purpose of the present preliminary study was to examine the feasibility of ES strength exercise integrated into tennis training sessions during the preparatory season of competitive men and women players and the impact of the intervention on vertical jump, shuttle sprint, and stretch-shortening cycle performance. For the first time, we carefully quantified ES current amplitude and evoked quadriceps force during all the training sessions, and we aimed to obtain a linear progression of these training parameters from session to session (i.e., progressive ES strength training).

METHODS

Experimental Approach to the Problem

The 7-week experimental period started 2 weeks after the beginning of the preparatory training season and finished immediately before the competitive season. During this period, the players all took part in tennis sessions, which were supervised by the same coach (3 sessions per week; approximately 120 minutes per session). Also, one friendly match was played every week. The typical tennis session was divided into warm-up, main, and cool-down periods. Warm-up and cool-down lasted 10–15 minutes each and included light jogging, stretching, and trunk exercises. The main part of the tennis session included on-court skill training (fundamental and advanced strokes, attack/defense technical and tactical skills, coordination drills, and special situations with and without the racquet) and actual match play. Because the experimental subjects belonged to the same tennis team and were trained by the same coach, it was considered inequitable to adopt different strength training modalities and/or different strength training volumes within the same competitive group. Therefore, the same type and dose of ES treatment was proposed for all players (see Procedures) as a part of preseason tennis preparation. The ES training was incorporated systematically into tennis sessions during a 3-week period, and ES parameters (current amplitude and evoked force) were consistently recorded to determine the feasibility of the treatment. Maximal voluntary contraction (MVC) force of the quadriceps muscle, vertical jump height, and shuttle sprint time were tested at baseline (week 0) and at weeks 4, 5, 6, and 7 (1, 2, 3, and 4 weeks, respectively, after the ES program) to determine the effectiveness of the program.

Subjects

Twelve well-trained Italian tennis players (5 men and 7 women, mean age ± *SD*: 23 ± 3 years, height: 171 ± 7 cm, mass: 63 ± 8 kg) competing at the regional and national levels (international tennis number ranging from 2 to 5) volunteered to participate in this study. Men reported regular tennis play for an average of 13.8 years (range 9–20 years), and women had played regularly for an average of 16.0 years (range 12–19 years). During the 6 months preceding the study, men had played an average of 5.2 $\text{h}\cdot\text{wk}^{-1}$ (range 4–8 $\text{h}\cdot\text{wk}^{-1}$), and women had played an average of 5.3 $\text{h}\cdot\text{wk}^{-1}$ (range 3–8 $\text{h}\cdot\text{wk}^{-1}$). All the players had prior strength training experience but not during the 6 months preceding the study. None of them had experienced ES strength training in the past. Subjects gave written, informed consent before the experiment, and the ethical approval for the project was obtained from the local committee on human research. The study was conducted in accordance with the Declaration of Helsinki.

Procedures

Electrostimulation Training. The 3-week ES training program consisted of 9 sessions (3 sessions per week) integrated into the tennis training sessions. In general, ES was completed before tennis activities and lasted approximately 16 minutes (3 minutes of warm-up, 10 minutes of strength training, and 3 minutes of cool-down). Bilateral ES of the quadriceps muscles was performed with the subjects seated on a custom-built leg extension machine, under isometric conditions. This machine, used for both training and testing, was equipped with a strain gauge (Globus, Codognè, Treviso, Italy) to measure both the level of ES evoked force and the MVC force. Both knee joints were flexed at 80° (0° = full extension), and a series of straps was applied across the pelvis to minimize hip and thigh motion during the contraction. The ES was delivered by a commercially available unit (Compex, Medicompex SA, Ecublens, Switzerland) using self-adhesive surface electrodes (2 mm thick). For each lower limb, 2 positive electrodes (5 × 5 cm) were placed over the motor point of the vastus medialis and vastus lateralis muscle, with the negative electrode (10 × 5 cm) positioned close to the proximal insertion of the quadriceps muscle (3–5 cm below the inguinal ligament). Biphasic symmetric rectangular-wave pulsed currents (85 Hz) lasting 400 microseconds were delivered with a rise time of 0.75 seconds and a fall time of 0.5 seconds. Each 4-second steady tetanic stimulation was followed by a pause lasting 25 seconds, during which subjects were submaximally stimulated at 4 Hz. The subjects were asked to fully relax their thigh muscles during the stimulations. In these conditions, each individual completed 20 isometric stimulated contractions (~10 minutes), which were consistently preceded and followed by 3 minutes of submaximal low-frequency ES (5–9 Hz; pulse duration ≈ 350 microseconds). Subjects were consistently asked to increase ES current amplitude (range 0–120 mA) throughout each training session and from session to session to attain the highest tolerable level without discomfort. For each subject and for each of the 9 training sessions, the average current amplitude (for both vastus lateralis and vastus medialis muscles) and evoked quadriceps force were recorded.

Testing. A standardized warm-up lasting approximately 15 minutes was carried out before each testing session and consisted of several submaximal contractions of the lower-limb muscles (e.g., jogging, squats, knee extensions, vertical jumps). Then, the MVC force of the quadriceps muscles was assessed under the same experimental conditions used for training (see above). Subjects were asked to perform isometric MVCs (duration 3–4 seconds) with real-time visual feedback. They were consistently given instructions on how to contract their knee extensor muscles (progressive rate of force development). Subsequently, vertical jump height and shuttle sprint time were measured using an optoelectronic system (Optojump, Microgate, Bolzano, Italy) (18) positioned on a carpet tennis court, to take into account the specificity between testing procedures and actual game play. Athletes performed the following vertical jumps: squat jump (SJ) and countermovement jump (CMJ) with the hands maintained on the hips, as well as 6 seconds of consecutive jumps (6J) while minimizing knee flexion and freely moving the upper limbs. In each case, the height of jump was calculated by using the flight time. The stretch-shortening cycle performance was evaluated from the jump heights of CMJ and SJ (Δ CMJ-SJ, in centimeters) as an augmentation by a prior stretch (15). Finally, subjects were asked to run the 2 × 5-m and 2 × 10-m shuttle sprint tests (26) as fast as possible, both with changing direction. Whatever the testing modality, subjects were requested to exert a maximal effort (MVC, jumps and sprints) 3 times, with 2–3 minutes of rest between trials. Only the best performance was included in the analysis. The tests used in this study demonstrated excellent test-retest reliability, with intraclass correlation coefficients (2,1) ranging from 0.86 to 0.98.

Statistical Analyses

The Pearson product-moment correlation coefficients were calculated for pairs of variables (ES current amplitude and evoked force as a function of time). A 1-way repeated-measures analysis of variance was performed on dependent variables (MVC force, SJ height, CMJ height, 6J height, Δ CMJ-SJ, 2 × 5-m time, and 2 × 10-m time). When a significant time effect was observed, Tukey HSD post hoc analyses were used. Alpha values were set to $p \leq 0.05$.

Results

The subjects' ES treatment compliance was 100%. Current amplitude for both vastus medialis and vastus lateralis muscles progressively increased throughout the 9 training sessions ($r^2 = 0.99$; Figure 1A). Similarly, the average level of evoked force increased from about 200 N (first ES session) to about 800 N (last ES session) ($r^2 = 0.95$; Figure 1B). Current amplitude and electrically evoked force during the 9 ES sessions were strictly correlated ($r^2 = 0.97$). The mean (± *SD*) evoked quadriceps force throughout the 9 sessions was 77 ± 21% of the pretraining MVC force.

The MVC force of the knee extensor muscles significantly increased during the entire duration of the experiment ($p < 0.001$), with the highest mean value observed at week 6 (Figure 2). A significant time effect was also observed for CMJ ($F = 4.2$; $p = 0.0057$), Δ CMJ-SJ ($F = 2.7$; $p = 0.041$), and 2 × 10-m sprint ($F = 3.6$; $p = 0.0125$). A tendency was observed for 2 × 5-m sprint ($p = 0.063$), whereas SJ ($p = 0.279$) and 6J ($p = 0.785$) did not change significantly over time (Figure 3A). The subjects' CMJ height increased significantly from baseline at week 5 (+5.3%; $p = 0.043$) and week 6 (+6.4%; $p = 0.003$), respectively (Figure 3B). Similarly, Δ CMJ-SJ significantly increased between baseline (1.9 cm) and week 6 (3.3 cm; $p = 0.022$) (Figure 3B). Subjects' 2 × 10-m sprint times at week 6 were significantly shorter (−3.3%; $p = 0.004$) compared with pretraining (Figure 4). At the end of the study period (i.e., week 7), the heights of the different jumps and the times for the 2 sprints were not significantly different with respect to baseline.

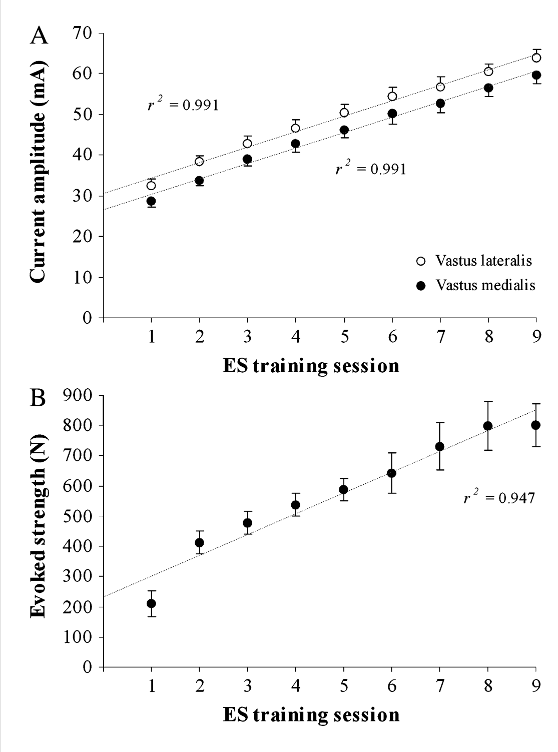

Figure 1. Current amplitude in milliamperes delivered to vastii muscles (A) and electrically evoked quadriceps force in newtons (B) linearly increased during the 9 electrostimulation (ES) training sessions. Values are mean ± *SE*.

Discussion

This preliminary study has demonstrated the feasibility of a short-term progressive ES training program incorporated into preseason tennis training of competitive men and women players. Treatment compliance was optimal and ES training parameters were progressively increased by the subjects themselves from session to session. Throughout the study period, we observed a delayed (i.e., 2–3 weeks after the end of

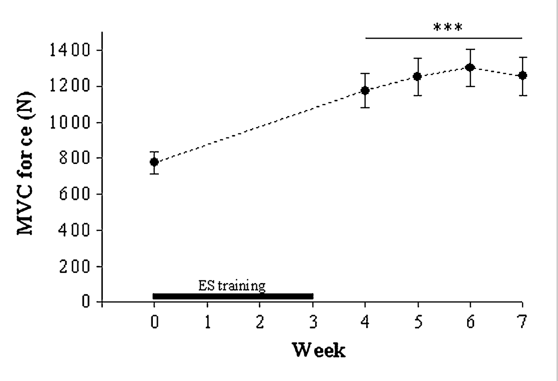

Figure 2. Quadriceps isometric maximal voluntary contraction (MVC) force before (week 0) and after the electrostimulation (ES) program (week 4–7). Values are mean ± *SE*. *** Significantly higher than baseline, $p < 0.001$.

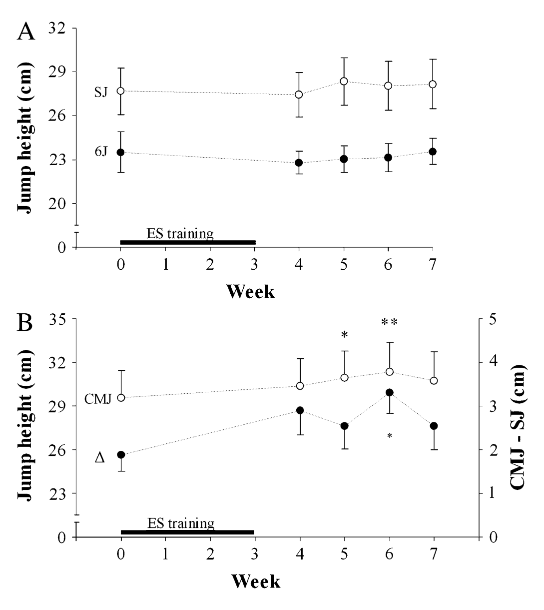

Figure 3. Vertical jump height for squat jump (SJ, open squares), 6-second jump series (6J, closed squares) (A), and countermovement jump (CMJ, open circles) and the difference between CMJ and SJ height (Δ, closed circles) (B) before (week 0) and after the electrostimulation (ES) program (week 4–7). Values are mean ± *SE*. *Significantly higher than baseline, $p < 0.05$; **significantly higher than baseline, $p < 0.01$.

the ES treatment) enhancement of CMJ height, stretch-shortening cycle performance, and 2 × 10-m shuttle sprint time. Because anaerobic power gains disappeared 1 month after the interruption of the ES strength training program, it is suggested that these benefits have to be maintained by means of other training techniques (e.g., plyometric training) during the preparatory and competitive season of tennis players.

Tennis is a physiologically demanding sport that requires several physical attributes such as power, speed, balance, agility, quickness, coordination, flexibility, and cardiovascular endurance (12). Because of the importance of muscular power (also termed "explosive" strength) in the game of tennis, strength training has become an important tool to optimize the neuromuscular performance factors related to the primary strokes (13,23). Some authors have already investigated the effects of voluntary strength training programs on muscle strength and power in competitive tennis players (10,13,14,24), but, to our knowledge, none have attempted to integrate artificial strength training into the tennis season. Successful completion of the present ES exercise program, together with tennis training and actual match play, may have contributed to improve quadriceps MVC force and anaerobic performance, as previously demonstrated for basketball (19), volleyball (20,22), rugby (1), and ice hockey players (3), but also stretch-shortening performance in both men and women tennis players. Girard et al. (8,9) have indicated that storage and use of elastic energy in lower-limb muscles would have a strong contribution for the effectiveness of the tennis serve, therefore emphasizing the importance of stretch-shortening cycle for tennis and the need for specific training programs such as plyometrics (4). Future research in this area may address the effect of ES vs. voluntary strength training on specific tennis activities, such as a tennis serve.

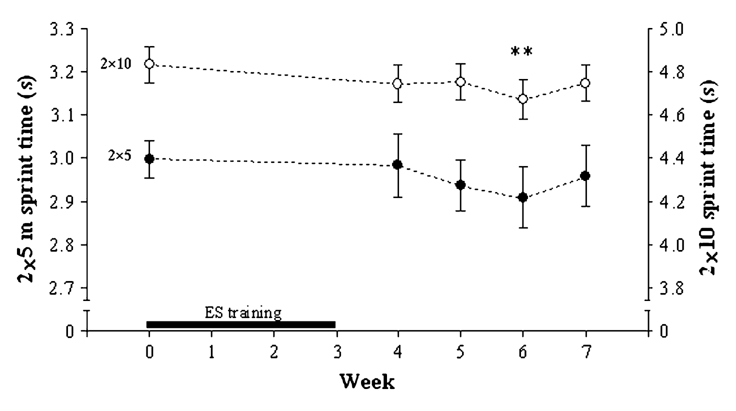

Figure 4. Time associated with 2 × 5-m (open diamonds) and 2 × 10-m shuttle sprint (closed diamonds) before (week 0) and after the electrostimulation (ES) program (week 4–7). Values are mean ± *SE*. **Significantly lower than baseline, $p < 0.01$.

Why should tennis players use ES strength training in addition to (or combined with) voluntary strength training? First, ES strength training programs are usually less time consuming than voluntary programs (22). The time schedule for physical conditioning is of paramount importance in tennis, especially for competitive players, and the preparatory period is typically too short to build a solid base level of fitness. Professional players participate in a large number of tournaments, and the majority of them have only one 5-week preparatory period per year (25). In this study, 1 single session of ES strength training lasted only 10 minutes (i.e., 30 $\text{min}\cdot\text{wk}^{-1}$), so ES was easily integrated into tennis sessions. As a speculation, voluntary strength training protocols usually require more than 30 $\text{min}\cdot\text{wk}^{-1}$ (13,14), and therefore additional training sessions should be included in the weekly time schedules of competitive tennis players.

Second, the pattern of motor unit recruitment imposed by ES is quite different from natural activation–that is, non-selective, spatially fixed, and temporally synchronous, favoring fast motor unit activation at relatively low force levels (11). For highly trained athletes, ES training over a short-term period could represent a new form of stress promoting adaptive changes, mainly within the central nervous system (e.g., increased muscle activation) (21).

Third, the results obtained in this preliminary study demonstrate that ES strength training incorporated into preseason tennis sessions can lead to significant but delayed improvements in CMJ, shuttle sprint, and stretch-shortening cycle performance without interfering with sport-specific tennis training. The fact that these beneficial effects disappeared 1 month after the end of the treatment (i.e., no difference was observed between baseline and week 7) as tennis practice was still maintained suggests that the observed changes were probably the result of ES and not the combined effect of ES and tennis. However, it is possible that a voluntary strength training program would have promoted similar or even greater changes in anaerobic performance characteristics compared with this present study. Future studies will examine the feasibility and efficacy of ES vs. voluntary strength training programs for professional tennis players.

PRACTICAL APPLICATIONS

Short-term, progressive ES strength training could be easily integrated into the preparatory tennis training seasons of men and women players. Optimal treatment compliance and a linear progression in ES training parameters (current amplitude and evoked force) could result in beneficial but delayed effects on anaerobic power and functional performance. Even if volitional exercise may be equally or more effective than ES exercise (2), short-term ES strength training programs may provide an advantage over voluntary strength training modalities when the time available for physical conditioning is limited. It is suggested that ES strength training could be efficiently used early in the tennis training season, and it also could be conducted during the in-season conditioning. Finally, ES of the quadriceps muscle should be considered as a valid adjunct to, rather than a replacement of, voluntary exercise.

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