

SURFACE EMG AS A METHOD FOR FOLLOWING-UP SPORTS TRAINING EFFICIENCY

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The purpose of the present study was to evaluate the applicability of surface electromyography (EMG) for evaluation of training related changes in muscle contractile properties. Eight nationally ranked junior tennis players participated in a six weeks training program designed to increase speed and explosiveness. Their physical characteristics were evaluated before and after the training period by: tennis-specific field tests, measuring isometric twitch contraction of the medial gastrocnemius muscle, and by monitoring the frequency spectrum of the EMG at 50% of the maximal voluntary contraction. All the players improved the results of tennis specific field tests after the training period, but only three players were recognized to increase contractile speed of the medial gastrocnemius muscle expressed by shorter twitch contraction times after the training period. The same three players exhibited higher characteristic frequency (defined as the mean frequency lying between the sixth and ninth decile of the spectral distribution function) and a wider EMG amplitude spectrum after the training period. A good correlation was found between the number of the parameters of the isometric twitch contraction that were improved by more than 2% after the training period (N_p) and the ratio between characteristic frequency after the training period (f_A) and characteristic frequency before the training period (f_B) (f_A/f_B) ($p = 0.0065$), as well as between N_p and the slope of the linear approximation of the dependence between decile frequencies of the EMG signal after the training period (dAf) and decile frequencies of the EMG signal before the training period (dBf) ($dAf = f(dBf)$) ($p = 0.0035$).

The correlation between the number of parameters of the isometric twitch contraction that were improved after the training period and the changes in characteristic parameters of EMG suggests the applicability of EMG for following-up sports training efficiency.

Keywords: Twitch contraction, contractile properties, surface EMG, spectral analysis, tennis.

INTRODUCTION

Adolescents' reasons for participation in sports are largely influenced by their psychological state of development. Their feelings about a sport are mostly related to their enjoyment, having fun and affiliation in a group while the extrinsic values such as winning and trophies become a primary motivational factor later in their career (Lee et al., 2000). Trainers spend a significant amount of time with adolescents during training days. They have to ensure that positive benefits arise from children's sporting experience like positive changes in their self-esteem, developing realistic expectations and persisting in physical activity through their later life. On the other hand they are obliged to encourage and promote talent development leading to the highest levels of accomplishment. The evaluation of physical progress due to chosen training methods is indispensably important for talent development, but it is a toilsome task due to adolescents' changeable motivation. Therefore, methods for physical progress evaluation that are independent of motivation are of crucial importance for coaches' work, because only objective information that

is promptly translated into practical training methods can assist athletes with both the enhancement of performance and the prevention of injury. Such methods are tests like the pulmonary function and total blood chemistry evaluation, indirect calorimetry, electrocardiographic work-up, body composition assessment and measurements of muscle contraction dynamics. Results provide information on the individual's physical health status and by periodical measurements the coach can critically review the effect of current training protocols.

Muscle contraction dynamics, particularly their contractile properties, are frequently evaluated by measuring whole muscle twitch (Rich & Cafarelli, 2000; Troup et al., 1986; Alway et al., 1989). Muscle twitch contraction characteristics depend on muscle histochemical properties. It has been shown that muscles with a higher percentage of type II fibers show shorter twitch contraction times (Hamada et al., 2000). On the other hand the relationships between proportions of muscle fiber types and areas and frequency content of EMG have been observed (Kupa et al., 1995; Seki & Narusawa, 1998; Gerdle et al., 2000; Larsson et al., 2001).

In the unfatigued state, positive correlations between the proportion of type II muscle fibers and the mean frequency of the power spectrum have been reported for the gastrocnemius, vastus lateralis and trapezius muscles (Gerdle et al., 2000). Many studies have indicated that specific training induces changes in twitch contraction characteristics (Rich & Cafarelli, 2000; Alway et al., 1989; Harridge et al., 1998) and authors have also reported that specific training induces changes in the surface EMG parameters (Rich & Cafarelli, 2000). Consequently we have anticipated that a relationship exists between training induced changes in twitch contraction characteristic and changes in surface EMG parameters in the frequency domain.

In this work we focused on tennis, a game which demands from an athlete a sustained high level of technical, tactical, psychological and physiological ability due to its complexity, speed, dynamic nature and the long duration of the match. Tennis play requires a high level of physical fitness related to such factors as strength, power, muscular endurance, flexibility, coordination and agility (Roetert & Ellenbecker, 1998). Both upper and lower body power are necessary. Upper body strength is needed to achieve efficient strokes. On the other hand lower body strength is required for sprinting to the ball, changing directions, stretching, stopping and starting, and balance (Roetert et al., 1996). After all, muscular endurance is important owing to the long duration of the match. Roetert et al. (1992) reported that in young male tennis players agility and speed have a higher correlation to tennis performance than is the case for any other physical performance factor. Players with explosive first steps get into position quickly, set up well, and hit effective shots (Roetert & Ellenbecker, 1998). In addition, an explosive first step gives players the speed necessary to get to the ball, when it has been hit far away (Roetert et al., 1995). Owing to the complexity of tennis, a measuring technique that could give the coach proper estimation of the player's physical progress in view of speed and explosiveness would be a great benefit. It should be independent of the observer, the player's knowledge of the test, footwear, weather and psychological factors such as motivation.

The main purpose of the present study was to evaluate the applicability of surface electromyography (EMG) as a non-invasive and pain-free technique for the evaluation of training related changes in muscle contractile properties. Thus, a group of junior tennis players went through a six week period of an intensive training program designed to increase speed, agility and explosiveness. Players' physical progress due to the training program was evaluated in three ways: (1) classically, by tennis-specific field tests, (2) by measuring isometric twitch contraction of the medial gastrocnemius muscle, and (3) by monitoring the frequency spectrum of the

surface EMG at 50% of the maximal voluntary contraction. Our hypothesis was that training would increase the contractile speed of the medial gastrocnemius muscle, which could be observed through the changes in twitch contraction characteristics. In the next step of the study, the correlation between the changes in twitch contraction characteristics and changes in surface EMG parameters in frequency domain was tested.

METHODS

Eight nationally ranked junior tennis players (mean (max/min) age: 12.7 (15/12) years) participated in the study. The players and their parents were informed about the experimental procedure as well as familiarized with the possible risks and discomfort before they gave their written consent. The tennis players performed a set of tennis-specific field tests and were subjected to a set of biomechanical measurements before the six week period of the intensive training program. After this period, the set of tennis-specific field tests and biomechanical measurements were repeated. Measurement protocols are described below.

Tennis-specific field tests:

Six tennis-specific field tests were chosen. Three of them (hexagon, spider run and sideways shuffle) are well known and described elsewhere (Roetert & Ellenbecker, 1998). As the fourth test the number of skips over a skipping rope in 30 s was selected and the task was named "skipping rope". The fifth test was denoted "3 × 30 s". The player started at the center of the service court. At the mark he/she ran to the singles sideline, touched the line with a racket, ran to the center service line, touched the line with his/her racket and so forth for 30 s. The task was repeated three times with two breaks of 30 s and the number of all touches was noted down. The last test was a "groundstroke shuffle". Two points were marked on the tennis court, both 3 m from the baseline and 1 m from each singles sideline. The player started at the center of the baseline. At the mark he/she ran to the left point, simulated one of the ground strokes (forehand or backhand) there, returned to the baseline, ran to the right point, simulated one of the ground strokes again, returned to the baseline, etc. The number of strokes in 30 s was scored.

Biomechanical measurements and electromyography:

The medial gastrocnemius muscle was selected for biomechanical measurements because it is one of the leg muscles that has to accommodate to explosive movement patterns and is highly involved in the push-off action of the forehand drive, backhand drive and volley (Roetert & Ellenbecker, 1998). During the meas-

urements the subject was seated in a comfortable chair with the knee flexed at a 90 degree angle. The ankle joint was aligned with the axis of rotation of the ankle joint torque meter consisting of a strain-gauge transducer that transformed the torque into voltage. Then the foot and shank were firmly fixed.

Twitch contraction:

Muscle dynamics was measured through isometric twitch contraction. An isometric twitch contraction was elicited by stimulating the medial head of the gastrocnemius muscle with a single, square wave stimulus of 0.5 ms duration and supramaximal intensity. The skin was slightly abraded and cleansed with ethyl alcohol. Bipolar, self-adhesive surface electrodes (Pals Platinum electrodes, Axelgaard Manufacturing Co., Ltd.) were placed on the skin, one on the motor point and the other near the tendon. We used a GRASS S88 stimulator (Grass Product Group, Astro-Med, Inc., West Warwick, USA), with voltage output, in conjunction with an insulation unit (SIU5 RF Transformer Isolation Unit, Grass Product Group, Astro-Med, Inc., West Warwick, USA). The measured muscle responses were stored to a computer and analyzed using Matlab 5.3 Software (Math Works, Inc., Natick, USA).

Five parameters were chosen for characterization of the isometric twitch contraction: T_{lat} : the latency period, i. e., the time between the stimulus and the beginning of the contraction; T_{50} : the time to half-tension, i. e., the time between the beginning of the contraction and 50% of the peak tension; T_{peak} : the time to peak tension, i. e., the time between the beginning of the contraction and the peak tension; T_{half} : the half relaxation time, i. e., the time between the peak tension and the half-tension of relaxation phase; α : inclination, i. e., the inclination of the torque curve at 50% of the peak tension.

Electromyography:

The subject was given verbal instructions in the performance of a maximal voluntary isometric contraction (MVC) of the medial gastrocnemius. The subject was then asked to perform the MVC for five seconds as a reference contraction, and the maximal voltage was marked. This maximal voltage served as the 100% MVC for the normalization procedure. The subject was then instructed to flex the ankle joint again and to maintain 50% of the previously determined maximum voluntary isometric contraction for 15 seconds. In the meantime (between the 5th and 10th second of contraction) one second of the surface EMG signal was sampled at 5 kHz and stored to a computer. EMG was measured and amplified (gain 100) by means of the commercially available Myolab II Model ML 200 system (Motion Control Inc., Salt Lake City, USA). Electrodes were placed on the muscles of the belly between the innervation zone

and the tendon in a direction parallel to the muscle fibers and fixed with elastic straps with Velcro attachments that were tightened just enough to hold the electrodes in place without obstructing blood flow. The position of the electrode was marked on the skin by a non-toxic ink pen to ensure the same electrode location in both measurements. The subjects were requested to maintain markings between sessions. The recorded EMG data were processed off-line using Matlab 5.3. We assumed that EMG signal was stationary during the measuring episode (Marletti & Lo Conte, 1995).

First, we filtered EMG data via the fifth-order Butterworth bandpass filter with the cut-off frequencies 10 and 500 Hz to eliminate frequency content of non-physiological origin (Clancy et al., 2002). A fast Fourier transformed (FFT) algorithm was performed to calculate its spectral characteristics. The spectral distribution function, defined as the normalized integral of the amplitude spectrum (i. e. the magnitude of the Fourier transform), was calculated (Lowery et al., 2000; Lowery et al., 2002). The location of each decile frequency was determined from this curve; for example, the sixth decile corresponds to the frequency below which occupies 60% of the area of the spectrum (Marletti & Lo Conte, 1997). The mean frequency between the sixth and ninth decile was defined as a characteristic frequency. This definition of characteristic frequency is based on the spectral distribution technique proposed by Lowery et al. (2000), who reported the mean shift in the midfrequency region (between the sixth and ninth deciles) of the EMG amplitude spectrum as a more accurate indicator of muscle fiber conduction velocity changes than the mean or the median frequency of either the power or amplitude spectrum.

RESULTS

Six players performed at least four tennis-specific field tests (from among six) before and after the six weeks training period. The results of all six tennis-specific field tests are shown in Fig. 1. The players as a group improved the results in the hexagon (paired t-test, $p = 0.001$), groundstroke shuffle (paired t-test, $p = 0.005$) and skipping rope (paired t-test, $p = 0.02$) tests. As can be seen from Figure 1, the players mostly improved also the results in the other three tests (spider run, sideways schuffle and 3×30 s), but the improvement of the whole group was not statistically significant. Three players (i. e., 2, 4 and 7) participated in all (i. e., six) tennis-specific field tests before and after the training period. After the training period, player 2 attained better results in all the six tennis-specific field tests, while the players 4 and 7 did not attain better results in one of the tests. Players 3 and 8 participated in the

five tennis-specific field tests before and after the training period. After the training period player 8 attained better results in all the five tennis-specific field tests, while player 3 improved the results of four tests. Player 6 participated in the four tennis-specific field tests before and after the training period and did not improve the results in one of the four tests. According to the chosen set of tennis-specific field tests all the players that participate in both testing periods enhanced their tennis performances after six weeks of special training since they attained better results in more than half of the tennis-specific field tests after the training period. Moreover they statistically significantly improved the results of a half tennis-specific field tests as a group.

The six weeks training period resulted in changes in isometric twitch parameters. If the parameters T_{lat} , T_{50} , T_{peak} and T_{half} were shortened by more than 2%, and the parameter α was increased by more than 2%, we assumed that the parameters were improved. One player (player 6) improved all five parameters of the isometric twitch contraction, and two players (player 2 and player 5) improved four. Five players improved just two (player 4 and player 8), one (players 1 and 3) or none (player 7) parameters. Only three players (i. e., 2, 5 and 6) improved more than half of the parameters of isometric twitch contraction and were therefore recognized to increase the contractile speed of the muscle after six weeks of special training.

After six weeks of special training the characteristic frequency of the medial gastrocnemius muscle increased in players 2, 5 and 6, decreased in players 4, 7 and 8, and petty decreased in players 1 and 3. It is interesting to note that before the beginning of the training, players 2, 5 and 6 had statistically significant lower (Student's t-test; $P = 0.025$) characteristic frequencies than the rest of the players. Good correlation between the number of the parameters of the isometric twitch contraction that were improved more than 2% in the second measuring period (N_p) and the ratio between characteristic frequencies after (f_A) and before (f_B) the training period (f_A/f_B) were found ($r^2 = 0.7357$, $p = 0.0065$). This result is presented in Fig. 2a. Fig. 3 depicts decile frequencies of the EMG signal after the training period (dAf) as a function of decile frequencies of the EMG signal before the training period (dBf) for each player. The amplitude spectrum of the EMG signal did not change during the training period in players 1 and 3, thus the function $dAf = f(dBf)$ is a straight line with the slopes 0.97 and 0.98 respectively. Also in the cases of players 2 and 5 the functions $dAf = f(dBf)$ are almost straight lines with a slope greater than 1 (1.14 and 1.12 respectively), i. e., the EMG amplitude spectrum after the training period was widened uniformly. The curve $dAf = f(dBf)$ of player 6 is not a straight line and its inclination is greater than 1, i. e., the EMG amplitude spectrum after

the training period was wider and had a different shape than the EMG amplitude spectrum before the training period. In the players 4, 7 and 8 the EMG amplitude spectrum after the training period is compressed with regard to the EMG amplitude spectrum before the training period; i. e., the inclinations of the curves $dAf = f(dBf)$ are under one. For the players 4 and 8 the curves are almost straight lines with slopes of 0.86 and 0.85 respectively, while the curve $dAf = f(dBf)$ of the player 7 differs from a straight line. As can be seen from Figure 2B, a good correlation was found between the number of parameters of the isometric twitch contraction that were improved in the second measuring period (N_p) and the slope of the linear approximation of the function $dAf = f(dBf)$ ($r^2 = 0.7831$, $p = 0.0035$). Again, the players 2, 5 and 6 were recognized as having increased the speed of the medial gastrocnemius muscle after six weeks of special training, since the EMG amplitude spectrum after the training period was wider.

DISCUSSION

All the players that participated in both testing periods improved the results of tennis specific field tests after six weeks of special training. However biomechanical measurements showed that the contractile properties of the medial gastrocnemius muscle were not equally changed in all players. Measurements of muscle twitch response showed that only three players (i. e., 2, 5 and 6) increased the muscle contraction velocity expressed by shorter isometric twitch contraction parameters T_{lat} , T_{50} , T_{peak} and T_{half} and increased α . After six weeks of special training the same three players exhibited also a higher characteristic frequency and wider amplitude spectrum of the EMG signal measured at 50% of the maximal voluntary contraction. Several authors reported that the type of muscle fibers influenced both the frequency content of EMG signals and the muscle contraction velocity. In general, higher values of the median or mean power frequency of the EMG power spectrum are observed for muscles with a greater proportion or relative area of type II fibers (Kupa et al., 1995; Gerdle et al., 2000; Bilodeau et al., 2003). Muscles with a higher content or larger area of type II fibers are also associated with shorter twitch contraction times that express the higher contraction velocity of these muscles (Hamada et al., 2000; Buchthal & Schmalbruch, 1970; Rice et al., 1988). Therefore, according to the literature and the results of the study we can conclude that medial gastrocnemius muscle fibers of the players 2, 5 and 6 adapted to special physical training. The adaptation resulted in an increase in the area (hypertrophy) or even in the content (hyperplasia) of type II fibers. The results of biomechanical measurements are in context

with coaches' observations and the opinion that players 2, 5 and 6 have high self-esteem, are highly motivated, competitive and value hard work. Each and all of them have also strong support from their parents.

We get a high correlation between the number of the parameters of the isometric twitch contraction that were improved in the second measuring period (N_p) and the slope of the function $dAf = f(dBf)$ obtained from EMG

measurements ($r^2 = 0.7831, n = 8, p = 0.0035$) as well as between N_p and the ratio between the characteristic frequencies f_A and f_B (f_A/f_B) ($r^2 = 0.7357, n = 8, p = 0.0065$). These relationships support the suggestions (Cifrek et al., 2000) that surface EMG as an objective, completely non-invasive and pain-free technique might be applicable as method for following-up sports training efficiency.

Fig. 1
The results of tennis-specific field tests

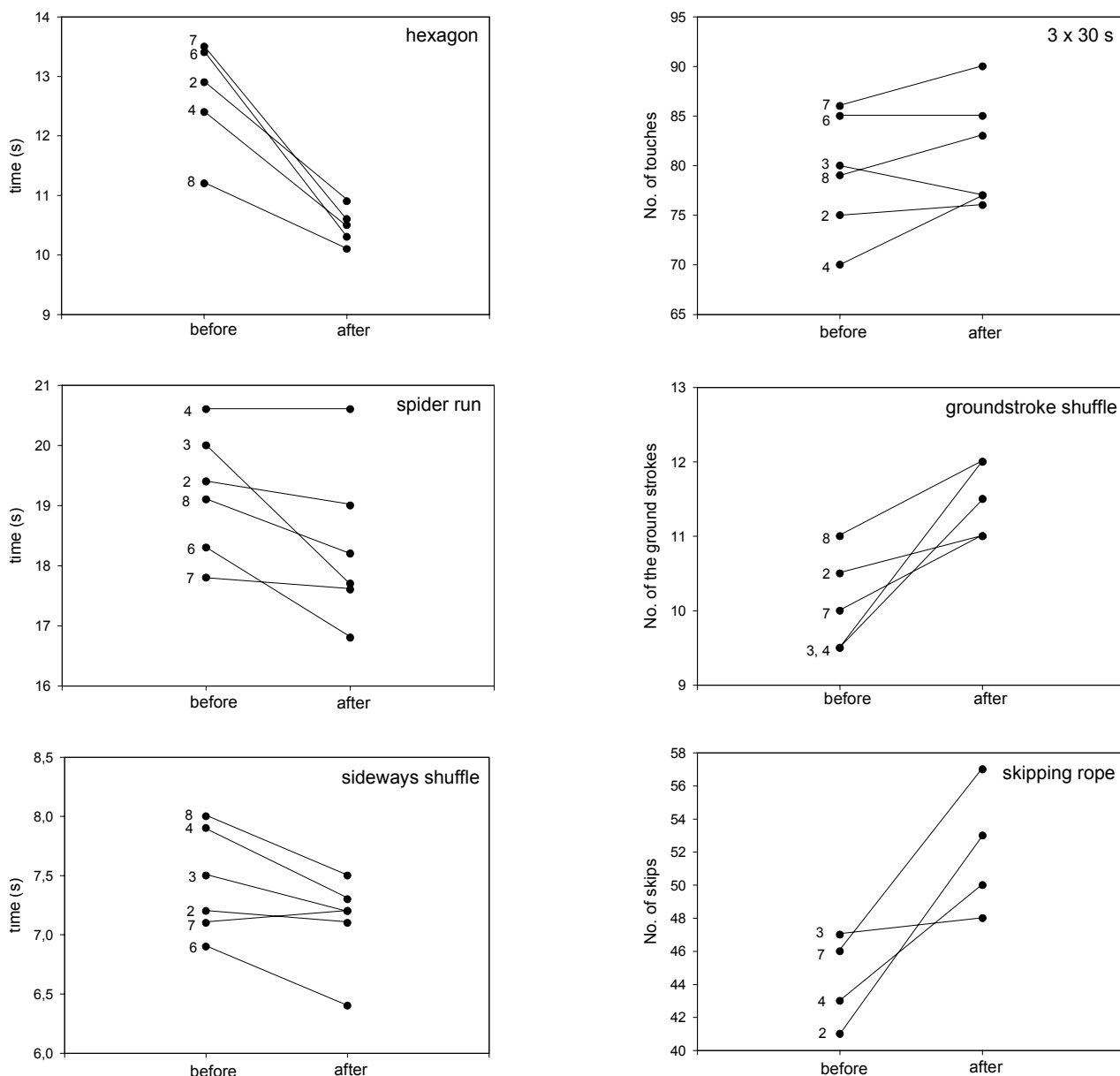
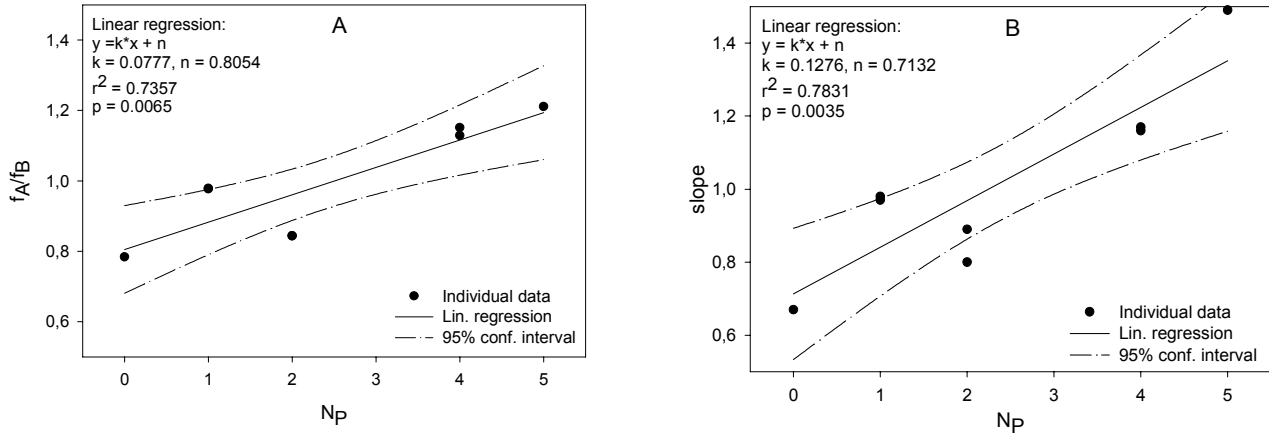


Fig. 2

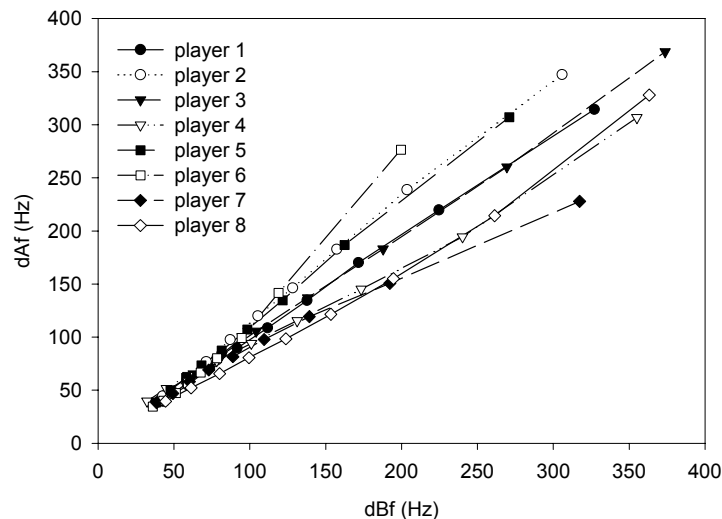
Correlation between two biomechanical methods:

A) Correlation between the number of the parameters of the isometric twitch contraction that were improved by more than 2% in the second measuring period (N_p) and the ratio between characteristic frequencies f_A and f_B (f_A/f_B)

B) Correlation between the number of parameters of the isometric twitch contraction that were improved in the second measuring period (N_p) and the slope of the linear approximation of the function $dAf = f$ (dBf)

**Fig. 3**

Decile frequencies of the EMG signal after the training period (dAf) as a function of decile frequencies of the EMG signal before the training period (dBf) for each player



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**EMG (ELEKTROMYOGRAFIE)
JAKO METODA PRO SLEDOVÁNÍ ÚČINNOSTI
SPORTOVNÍHO TRÉNINKU**
(Souhrn anglického textu)

Účel této studie byl zhodnotit vhodnost a použitelnost povrchové elektromyografie pro vyhodnocení změn kontrakčních vlastností svalů spojených s tréninkem.

Skupina osmi národních juniorských tenistů se zúčastnila šestitýdenního výcvikového programu, který byl zaměřen na zvýšení rychlosti a výbušnosti. Jejich fyzické charakteristiky byly zhodnoceny před a po období programu, a to specifickými tenisovými testy, které měří izometrickou kontrakci trhnutí středního gastroknemického svalu, a zaznamenáváním spektra frekvence EMG při 50% maximální volní kontrakci.

Ve specifických tenisových testech se prokázalo, že většina hráčů zlepšila své výkony po výcvikovém období, pouze u 3 hráčů byla zjištěna zvýšená rychlost kontrakce středního gastroknemického svalu, která byla vyjádřena kratší dobou kontrakčního trhnutí po období výcviku. Stejní hráči předvedli vyšší charakteristickou frekvenci (definována jako střední frekvence ležící mezi 6. a 9. decilem spektrální distribuční funkce) a širší EMG spektrum rozkmitu po výcvikovém období. Vysoká korelace byla zjištěna mezi počtem parametrů

izometrické kontrakce trhnutí, která byla zlepšena o více než 2 % po období výcviku (N_p), poměr mezi charakteristickou frekvencí po období výcviku (f_A) a před výcvikovým obdobím (f_B) (f_A/f_B) ($p = 0,0065$), a také mezi N_p a stoupáním lineárního přiblížení závislosti mezi decilovými frekvencemi signálů EMG po období výcviku (dAf) a před výcvikovým obdobím (dBf) ($dAf = f(dBf)$) ($p = 0,0035$).

Korelace mezi počtem parametrů izometrické kontrakce trhnutí, které byly zlepšeny po období výcviku, a změny v charakteristických parametrech EMG evokují použitelnost EMG pro sledování účinnosti sportovního výcviku.

Klíčová slova: kontrakce trhnutí, kontrakční vlastnosti, povrchová EMG, spektrální analýza, tenis.

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