Trunk Muscle Activation in Open Stance and Square Stance Tennis Forehands

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Electromyography of the trunk muscles were compared between the open and square stance forehand drives of 14 collegiate tennis players. Surface EMG were bilaterally collected from the rectus abdominis (RA), external oblique (EO), and erector spinae (ES) in open and square stance forehand drives. EMG data were transferred by telemetry, 12 bit A/D converted at 1000 Hz, and stored for analysis. Rectified and smoothed EMG data were normalized (NEMG) to maximal isometric voluntary contractions and mean NEMG were calculated during the forward swing and followthrough phases of the stroke. A 2×2×2×6 factorial ANOVA (Gender, Stance, Phase, Muscle) with repeated measures on Subject showed significant ($p < 0.05$) effects of Gender, Muscle, Phase, and several interactions. The nonsignificant differences in muscle activation between stances did not support the belief of tennis experts that open stance forehands require greater trunk activation than square stance forehands. Mean NEMG of the ES were significantly ($p < 0.05$) larger than EO or RA, which was consistent with observations of tennis-specific strength imbalances and increasing incidence of low back injuries in tennis.

Key words: Abdominal, EMG, erector spinae, external oblique.

Introduction

The optimal execution of the forehand stroke in tennis has been a controversial issue for many years. Many tennis instructors of the early 20th century taught players that the shoulders should remain at right angles to the net throughout the forehand drive [21]. Early electromyographic (EMG) studies of the upper extremity in the tennis forehand were conflicting, concluding that the stroke had either ballistic muscle activation [1] or non-ballistic muscle actions [24]. Biomechanical studies later confirmed the existence of two kinds of coordination in the forehand drive, the single unit and a multi-segment forehand [2,8,15,26].

Recent changes in racket design have had an even more dramatic effect on the stroke techniques employed by tennis players [9,11]. The lighter, larger headed, and more powerful composite rackets have helped fuel the trend of more players using open stance (OS) forehand stroke technique, rather than classic square stance (SS) technique [11,18]. Tennis experts believe that the OS technique relies more on ballistic, angular momentum generated by the hips and trunk than the SS technique [10]. This potential reliance on the trunk and arm action, at the expense of linear momentum from the lower extremities, is hypothesized to increase the risk of overuse injuries [3,7,11,22] and contribute to strength imbalances [6]. Therapists treating tennis players report an increasing number of abdominal muscle strains that they attribute to greater use of the OS forehand technique [7]. Tennis conditioning programs have tended to emphasize trunk muscle training and specifically trunk twist exercises [5,12,22].

Sports medicine professionals hypothesize that trunk muscle forces are larger in the OS forehand than in the SS forehand [7,22]. Initial studies of the three-dimensional kinematics [16] of the open and square stance forehand have only observed minor differences between the two techniques with a small decrease in trunk angular velocity in the OS technique just prior (40 ms) to impact that was not observed in the SS. EMG studies of SS forehands have observed low (<25% MVC) abdominal muscle activation [4,19] and larger (60% MVC) erector spinae activation. There have been no EMG studies of the OS and SS forehand drive that would help clarify the issue of differences in trunk action in the two techniques. Data are needed to provide objective evidence of the hypothesis of reliance on greater trunk muscle contribution in the OS forehand compared to the SS forehand. The purpose of this study was to compare the rectus abdominis (RA), external oblique (EO), and erector spinae (ES) muscle activation in the OS and SS tennis forehands.

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Material and Methods

Subjects

Eight male and six female right handed intercollegiate tennis players volunteered and gave informed consent according to the policies set by the Institutional Review Board for the Protection of Human Subjects at the University of San Francisco. Subjects had a mean (sd) age of 20.4 (2.6) years, weight of 70.0 (12.4) kg, and 8.4 (4.2) years of playing experience. All subjects were either past or present members of the University of San Francisco tennis team and reported no recent injuries related to tennis stroke production.

Data collection

Surface EMG data were collected bilaterally for the rectus abdominis (RA), external oblique (EO), and erector spinae (ES) using the electrode placement described by Juker and colleagues [14]. Subject's skin was cleansed with alcohol and slightly abraded with sandpaper prior to electrode placement. Disposable 15 mm electrodes (Blue Sensor M-00-S) were attached to the skin parallel to the apparent direction of the muscle fibers. A ball-racket impact signal was generated by two strain gauges bonded to the opposite sides of the racket.

EMG signals were collected and transmitted by FM telemetry using the Noraxon® hardware and MyoResearch© software. Strain gauges were amplified and hardwired to an A/D converter. Strain and EMG data were 12 bit A/D converted at 1000 Hz and stored on computer. EMG signals were amplified (gain of 400), band pass filtered (10 to 500 Hz), smoothed (t_c = 15 ms), and full-wave rectified. Signals were also observed through a direct connection to an oscilloscope to monitor for artifacts and a good signal-to-noise ratio.

Baseline data

Baseline EMG data were obtained by having subjects perform two maximal voluntary isometric contractions (MIVC) in each of three tests. The tests were designed to obtain maximum activation of the muscles being studied [14]. For the ES, MIVCs were performed against manual resistance as the subject lay prone on a table with the upper body extended over the edge and the lower body secured by research assistants. For the RA and EO, the subject lay supine with hips and knees flexed and feet secured by an assistant. Subjects crossed their arms across their chest and attempted to curl up against manual resistance. Curl-ups were performed with attempts to twist the trunk so the shoulder approached the contralateral knee, two to the left and two to the right. MIVC tests were held for three seconds with one minute rest between tests.

Forehand trials

Stroke data were collected on a tennis court set-up on a hardwood gymnasium. After preparation and baseline data collection, subjects watched an instructional video that illustrated the differences between the square and open stance forehand. Subjects then warmed-up and hit 10 practice forehands of each style to become familiar with the conditions. An investigator (JB) who was a former tennis teaching professional monitored the performances of each stroke to ensure the correct style was used. New tennis balls were projected from a ball machine at 23 m/s to simulate a typical baseline to baseline rally. Projected balls bounced on a carpet square taped to the floor to more closely simulate the spin and bounce of outdoor matches. Subjects were instructed to stroke the ball directly over the net directly toward the ball machine using either a square or open stance. Square and open stance forehands were randomly assigned until 10 strokes of each type were completed. Sagittal plane videography (60 Hz) was used to later determine the appropriate temporal windows to document forward swing and follow through muscular actions.

Data analysis

Maximal EMG from a baseline test was calculated from the mean value of the rectified EMG of the middle second of the test because large windows for averaging increase reliability [27]. The maximum mean value for each muscle, regardless of which test produced it, was used to normalize (NEMG) the forehand data. Videography demonstrated that the forward swing and follow through phases of the strokes could be operationally defined as the 500 ms before impact and the 300 ms after impact, respectively.

Mean NEMG values were calculated for each muscle for the execution and follow through phases of each forehand technique. NEMG data were analyzed with a 2 × 2 × 2 × 6 factorial ANOVA (Gender, Stance, Phase, Muscle) with repeated measures on Subject. Statistical significance was accepted at the 0.05 level. Tukey-Kramer HSD post hoc tests were calculated for significant main effects with more than two levels.

Results

Factorial ANOVA demonstrated significant main effects for Phase ($F_{1,276}$ = 37.3, $p < 0.0001$), Muscle ($F_{5,276}$ = 56.6, $p < 0.0001$), and the interaction of Phase and Muscle ($F_{5,276}$ = 8.8, $p < 0.0001$). Phase, Muscle, and their interaction were the independent variables that accounted for most variance of NEMG (η^2 = 4.3, 33.0, and 5.1% respectively) in the forehand drive. Observation of the plotted means showed that much of the interaction was due to greater mean activation of the left ES (50.9%) in the forward stroke compared to the follow through (24.6%). Across all muscles, there was a nonsignificant ($F_{1,276}$ = 1.1, $p = 0.31$) trend of greater mean NEMG in the OS (23.6 ± 17.7%) compared to the SS (22.1 ± 18.1%).

There was a significant ($F_{1,276}$ = 9.4, $p < 0.002$) effect of gender with females having greater mean muscle activation (25.4 ± 18.1%) than the males (20.9 ± 17.6%). There was a significant ($p < 0.05$) three way interaction between Phase, Gender, and Stance, and there were significant ($p < 0.05$) two way interactions with gender: Phase by Gender and Muscle by Gender. The plots of mean NEMG of the muscles across gender show a similar pattern, so the significant Gender by Muscle interaction was likely due to slightly higher mean LEO and REO activity (25.2 and 33.2%) in the females compared to the males (13.4 and 22.8%). The physical importance of the gender effect (η^2 = 1.5%) and their interactions (η^2 = 2.4 and 0.5%) are therefore questionable based on the low variance in NEMG accounted for. Table 1 reports the mean NEMG values for the muscles, stances, and phases of the forehand drives pooled across gender.

Table 1 Mean (sd) NEMG of trunk muscles in the forehand drive

	Muscle						
	LRA	RRA	LEO	REO	LES	RES	(Mean)
Open Stance							
Forward Swing	9.7 (6.1)	12.7 (6.9)	22.8 (17.4)	34.9 (16.5)	50.9 (19.2)	33.9 (17.6)	27.5
Follow through	8.3 (6.0)	13.1 (7.1)	16.3 (17.7)	25.3 (13.5)	23.9 (9.0)	30.1 (13.7)	19.5
Square Stance							
Forward Swing	8.9 (5.9)	11.1 (5.1)	20.3 (19.7)	29.0 (11.7)	50.8 (18.0)	36.8 (18.4)	26.2
Follow through	7.2 (5.6)	12.2 (8.9)	14.3 (19.9)	20.0 (9.0)	25.2 (15.2)	30.7 (13.0)	18.3
Muscle Mean	8.5$^{*\tau\varsigma\xi}$ (5.8)	12.3$^{*\tau\varsigma}$ (6.9)	18.4$^{*\tau\varsigma}$ (18.4)	27.3* (13.7)	37.7 (20.3)	32.9 (15.7)	

Muscle activation in percent MIVC. L (left), R (right), RA (rectus abdominis), EO (external oblique), ES (erector spinae). Post hoc tests significantly ($p < 0.05$) different from LES*, RES$^{\tau}$, REO$^{\varsigma}$, LEO$^{\xi}$

Because the main effect of muscle was highly significant and accounted for the most variance in NEMC, Tukey-Kramer HSD post hoc tests were conducted to examine differences in muscle activation in the forehand drive. It should be noted that the significant interactions could have an effect on these post hoc muscle comparisons. As could be expected, there was a significant ($p < 0.05$) main effect for Subject ($\eta^2 = 14.5\%$) on of muscle activation in the forehand drives. This was due to small differences in the magnitude of NEMG across subjects. Typical impact and rectified EMG signals observed in the SS and OS are presented in Figs. **1** and **2**.

Discussion

The data did not support the speculation of tennis experts that the OS forehand would require greater trunk muscle activity than the SS. There was a nonsignificant trend of greater activation of trunk muscles in the open stance ($23.6 \pm 17.8\%$) compared to the square stance ($22.1 \pm 18.1\%$). The similar muscle activity in the SS and OS technique of these subjects was not likely a Type II statistical error. The statistical power of the present study shows adequate power ($1 - \beta = 0.81$) for detecting real mean differences in NEMG between stances down to 1.8% of MIVC.

The significantly larger mean NEMG of the forward swing ($26.8 \pm 20.2\%$) compared to the follow through ($18.9 \pm 14.3\%$) could be due to less muscle activation to slow the racket or the smaller EMG observed in primarily eccentric compared to concentric muscle actions [17]. All the muscles studied had larger mean NEMG in the forward swing phase than in the follow through phase (Table **1**). This suggests that none of the muscles studied were specifically activated at high levels of eccentric action to slow the motion of the trunk or racket.

Across both phases of the forehand drive, post hoc tests ($p < 0.05$) demonstrated that mean LES activity was significantly larger than the mean activation of all the abdominal muscles studied. Mean RES activation was significantly larger than all the abdominal muscles except for the REO. The size of

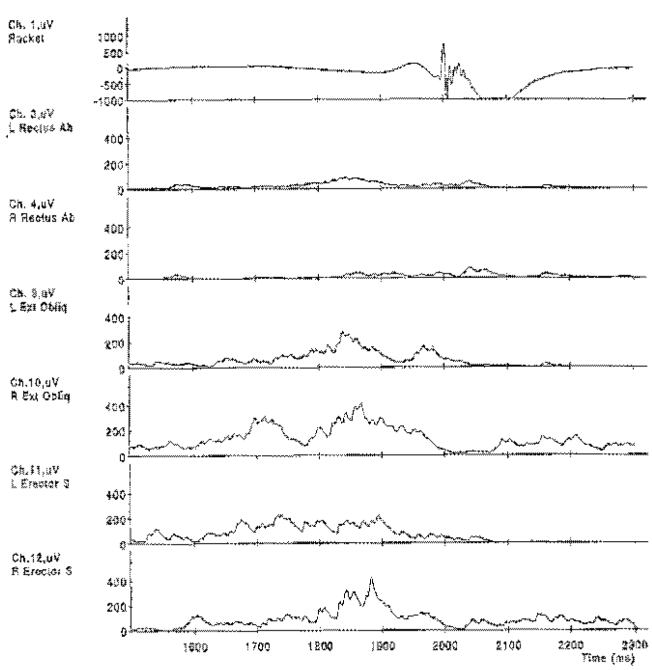

Fig. 1 Typical impact and rectified EMG signals of the trunk muscles for the square stance forehand.

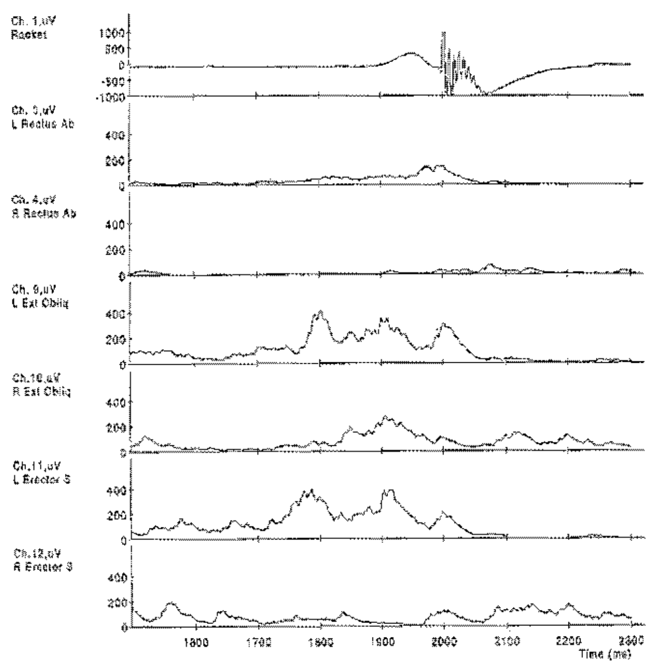

Fig. 2 Typical impact and rectified EMG signals of the trunk muscles for the open stance forehand.

the NEMGs observed and the greater trunk extensor activation than abdominal activation was in agreement with the results reported by Quinn [20]. Peak values of NEMG of the ES muscles in the forehands approached and occasionally exceeded 100% MIVC, while peak values of the abdominal muscles were lower and did not exceeded 100%.

The significant differences in trunk flexor and extensor activation supports the contention that tennis-specific strength imbalances in the trunk could develop if supplemental conditioning exercises are not performed [6]. This strong activation of the ES muscles in the forehand drives could also contribute to the clinical observations of increased incidence of low back injuries in tennis [13] and the above average trunk extensor strength observed in tennis players [23, 25].

The EO is commonly observed as the primary agonist to axial rotation of the trunk to the contralateral side [14]. The present data supported this in the forehand drive since REO had a mean activation significantly ($p < 0.05$) greater than the other abdominal muscles during the forward swing. Twisting abdominal exercises are likely to be an effective training modality for both styles of the tennis forehand drive. Although the gender effect on EO activation is small, it is consistent with recent observations of more longitudinally arranged (2–3 degrees) EO fibers in females compared to males [19]. More longitudinally oriented EO fibers would require greater activation to create the same axial torque as a more oblique fiber orientation.

The results of the present study did not support the hypothesis of greater trunk muscle activation in the open stance compared to the square stance. There were significant differences in the activation of specific muscles before and after impact. The data supported previous research on strength imbalances in tennis players because of marked ES activity, the importance of EO in axial rotation, and indicated that female players may require greater EO activity because of a less oblique fiber orientation of the EO. Since the data were collected in simulated stroking conditions with skilled players, the results may not be generalizable to other skills levels or match play conditions.

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