Lower trunk muscle activity during the tennis serve

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Prior electromyographic (EMG) analyses of the tennis serve have focused on the muscles in the hitting arm and shoulder region. This preliminary study aimed to examine the muscle activation patterns of selected lower trunk muscles during three different types of tennis serve - flat, topspin, and slice. Five male highly skilled tennis players completed 10 trials for each type of serve. Surface EMG electrodes were used to monitor the rectus abdominis (RA), external oblique (EO), internal oblique (IO), and lumbar erector spinae (ES) muscles. For each subject, the two trials with the highest self-reported ratings were analysed. Average EMG levels during each phase of a tennis serve for each muscle were analysed using a non-parametric ANOVA design. No major differences in muscle activation pattern were found across different serve types, and bilateral differences in muscle activation were more pronounced in RA and EO than in IO and ES muscles. The abdominal muscles were more active in the topspin than in the other two types of serves during the upward swing of the racket. An appreciable amount of abdominal/low back and bilateral co-activation was observed during certain phases of the serve. The co-activation of lower trunk muscles may help to stabilise the lumbar spine during the arch back and forward swing phases of the serve. The results reinforce the importance of abdominal and low back exercises in the strength and rehabilitation programs designed for tennis players.

Introduction

Prior electromyographic (EMG) analyses of the tennis serve have focused on the muscles in the hitting arm and shoulder region(1-6). Very limited data on the activity of the lower trunk muscles during the tennis serve are available. One study by Anderson(1) reported that both the left and right external oblique muscles were very active (greater than 50% of the muscle's peak level of activity) during the force production phase of the tennis serve.

The three types of serves that are widely used in tennis are the flat (minimum spin), topspin, and slice (sidespin) serves. Because the racket movement pattern and ball contact location relative to the body are different among these serves(7-9), it was hypothesised that the muscle activation patterns of lower trunk muscles are not the same for these three types of serves. To expand our understanding on muscle functions during the tennis serve, this preliminary study compared the EMG activity of selected abdominal and low back muscles during three different types of tennis serves. In addition, co-activation and bilateral differences in muscle activation were also examined.

Methods

Five male intercollegiate tennis players (US national tennis rating 5.5 or higher) with no known musculoskeletal disorders served as subjects (age 19±1 years, height 187±8 cm, mass 83±2 kg). Highly skilled players were preferred because they exhibited more consistent muscle activation patterns than beginners when performing tennis serves[10]. Because highly skilled players are likely to be a homogenous group in terms of stroke production, we anticipated that meaningful differences across different serve types could be detected despite the small sample size. All subjects were right-handed and used their own rackets when the data were collected. They signed informed consent documents before their participation.

Testing sessions were conducted in an indoor tennis facility. Eight pairs of surface EMG electrodes with on-site preamplification circuitry (Liberty Technology MYO115 electrodes, gain= 1,000, input impedance $>10^{14}$ Ω, CMRR >90 dB) were used to monitor the left and right rectus abdominis (RA), 3 cm lateral to the umbilicus; external oblique (EO), approximately 15 cm lateral to the umbilicus; internal oblique (IO), below the external oblique electrodes and just superior to the inguinal ligament; and lumbar erector spinae (ES), 3 cm lateral to L3 spinous process[11].

To obtain maximum EMG levels, two maximal isometric exercises were performed: the bent-knee sit-up with the trunk inclined at approximately 30° to the horizontal and the trunk hyperextension performed in the prone position. Three trials were performed for each exercise and each contraction lasted for about 3 s. The EMG signals were further magnified using a general purpose amplifier (input impedance = 10^9 Ω, CMRR >100 dB, nonlinearity <0.01%) before A/D conversion (12-bit) at a sampling rate of 1,000 Hz. The electrode wires were of sufficient length (4 m) such that the serving motions were not hindered.

The subject was asked to perform three different types of serves from the advantage court (left side of the baseline) - flat, topspin, and slice - with efforts comparable to their first serves and to target their serves at the corner of the service box near the sideline. Ten trials were completed for each type of serve and the order of the type of serve was assigned randomly. At the end of each trial, the subject rated his own performance based on both ball placement and speed using a 5-point scale (5= excellent, 0= poor). For each trial, the EMG signals were collected for 5 s. The serving motions were recorded using a S-VHS camcorder (60 fields/s) located near the left (advantage court) net post. To synchronise the video and EMG data, a synchronisation unit connected to a large light emitted diode (LED) and the A/D converter was manually activated during the time the EMG signals were sampled.

For each subject, the two trials with the highest ratings for each serve type were analysed. The average rating of the trials analysed was 4.5. The raw EMG signals were filtered using a recursive digital filter (Matlab Elliptic filter, 10-500 Hz band pass) and full-wave rectified. The maximum isometric trial data were smoothed using a moving average of 2 s and the largest average EMG value recorded for each muscle was considered the maximum EMG level. The experimental trial data were smoothed using a moving average of 50 ms before normalising to the respective maximum EMG levels.

For each trial being analysed, six instants were identified from the video

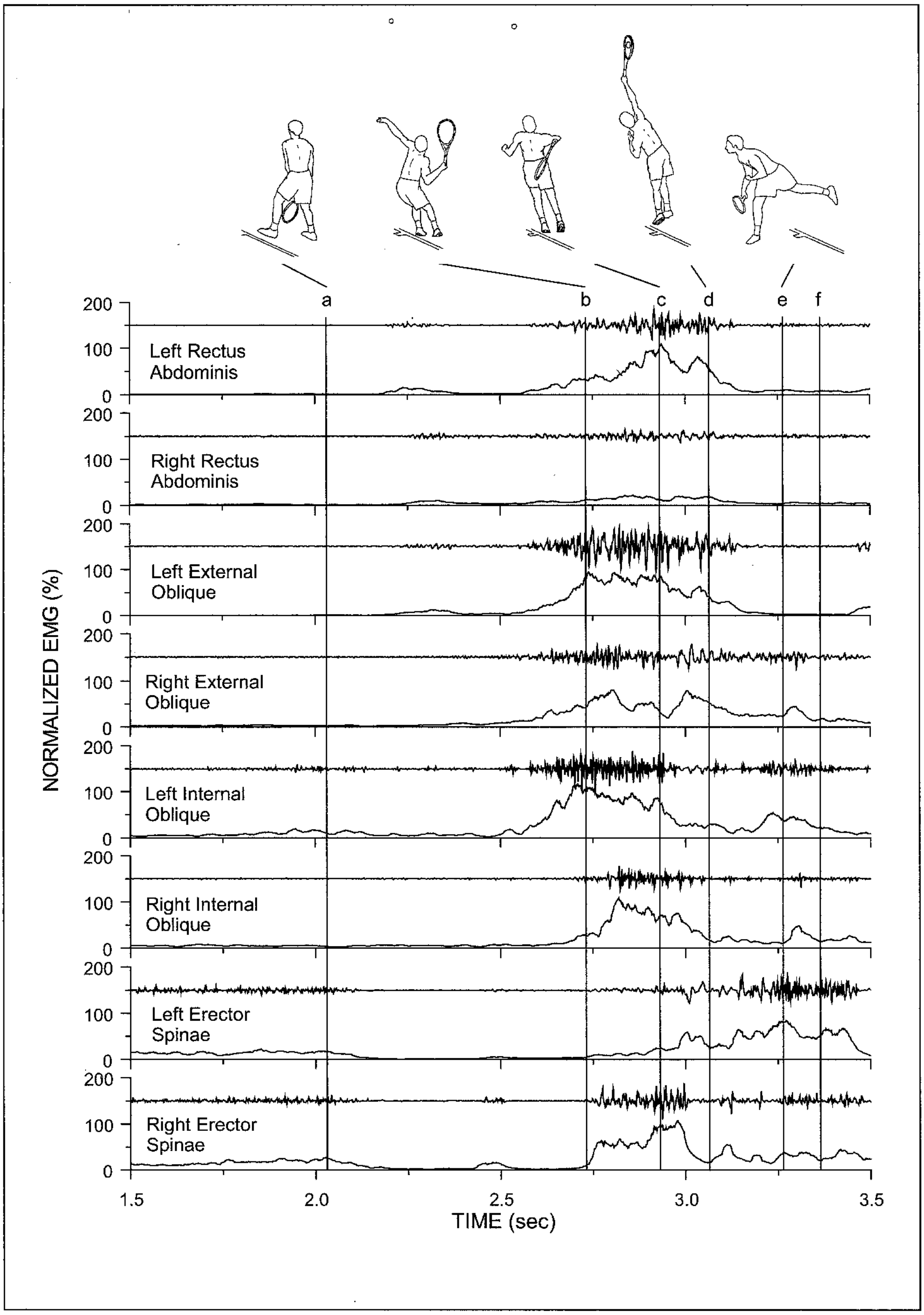

Figure 1: Raw and rectified and normalised EMG data obtained from a topspin trial. The vertical lines indicate the critical instants - (a) beginning of the ascending windup, (b) end of ascending windup, (c) end of descending windup, (d) ball impact, and (e) landing, and (f) end of the follow-through phase.

recordings (Figure 1): (a) the racket passes in front of the legs, (b) the racket reaches the highest position, (c) the racket reaches the lowest position behind the trunk, (d) ball impact, and (e) the subject lands on the court. These instants were used to define five phases: ascending windup (from instant a to b), descending windup (b to c), acceleration (c to d), early follow-through (d and e), and late follow-through (the duration of 0.1 s after the instant of subject landing).

For each subject, average normalised EMG values over two trials of the same serve type were used for subsequent analysis. For each muscle in each phase, a Friedman test was used to test for significant differences ($p \leq .05$) in average normalised EMG value across serve types. Post hoc pairwise comparisons were completed using the Scheffé tests. Using the average across the serve type, a Wilcoxon test was performed to test for significant differences ($p \leq .05$) in average normalised EMG values between the left and right muscles in each phase.

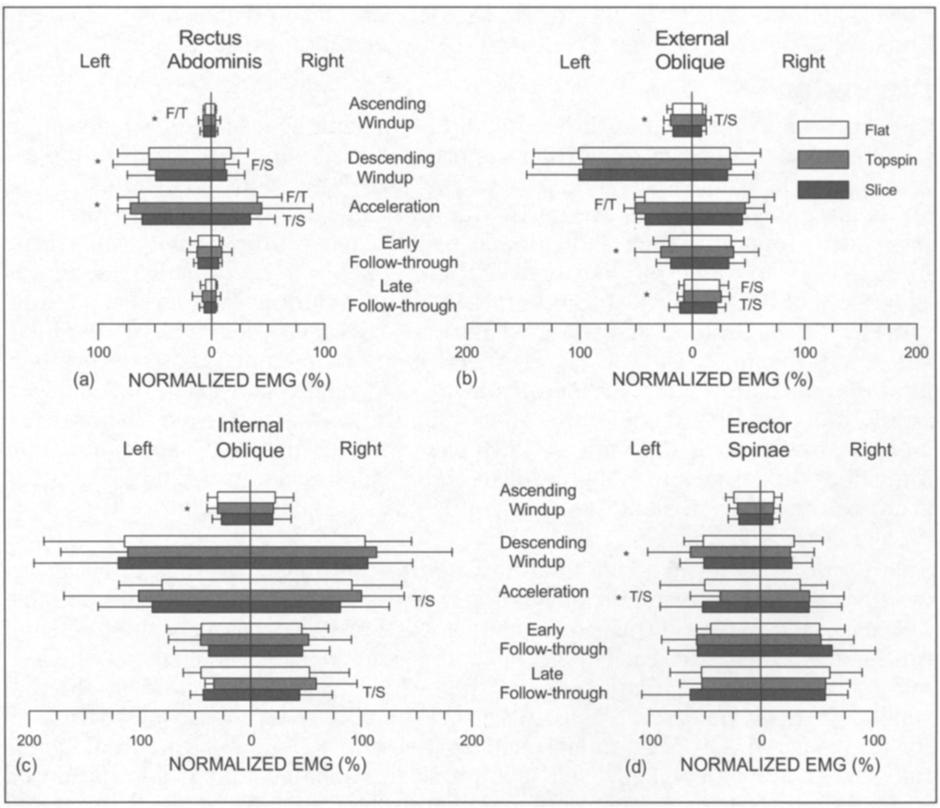

Figure 2: Average EMG levels of the (a) rectus abdominis, (b) external oblique, (c) internal oblique, and (d) erector spinae muscles during different phases of the tennis serve. Significant differences were found between the left and right muscles (*), flat and slice (F/S), topspin and slice (T/S), and flat and topspin (F/T) serves. The error bars indicate standard deviations.

Results

In general, the lower trunk muscles became active toward the end of the ascending windup phase (Figure 1). Peak EMG values were observed in either the descending windup or acceleration phases. Regardless of the serve type, the left RA showed greater activity than the right RA in all phases of the serve (Figure 2a).

Significant bilateral differences in EMG activity were found in the RA during the ascending windup (average absolute difference= 2.5%), descending windup (38.5%) and acceleration (25.5%) phases (Figure 2a), EO during the ascending windup (7.1%) and early and late follow-through (12.6% and 15.4%, respectively) phases (Figure 2b), IO during the ascending windup phase (7.0%) (Figure 2b), and ES during the descending windup (26.3%) and acceleration (5.0%) phases (Figure 2b).

Significant differences in EMG activity across different serve types were found in the left RA during the ascending windup phase, right RA during the descending windup and acceleration phases (Figure 2a), left EO during the acceleration phase, right EO in the ascending wind up and late follow-through phases (Figure 2b), right IO during the acceleration and late follow-through phases (Figure 2c), and left ES during the acceleration phase (Figure 2d).

Discussion

The type of subject used in this study did not permit generalisation of findings beyond highly skilled tennis players and the limited sample size prevented us from drawing conclusive statements. The large variations in average EMG levels among the subjects are partly due to the normalisation procedures. In has been reported that individuals exhibit maximum activity of trunk musculature in different postures(12). There appears to be no single isometric exercise that is best for all subjects for eliciting maximum EMG level of a trunk muscle. As a result, over-estimated normalised EMG levels will be obtained when sub-maximal EMG levels are used in normalisation. In spite of these limitations, the EMG activity does indicate the general activation of the lower trunk muscles during different phases of the tennis serve and allows for comparisons among different serve types. Another possible explanation for individual differences in EMG patterns is the differences in the initial stance, grip, toss, swing path, and point of contact among players even for the same type of serve(13).

Partly due to the relatively long duration of the phase, average EMG levels were generally low during the ascending windup phase. Qualitative inspections of EMG activity during this phase confirmed that there was very little activity until after the ball release (Figure 1). It seems reasonable to assume that minimising the trunk motion at the time of ball release will help produce a consistent toss. However, this point is rarely emphasised in the instruction of the tennis serve. Although muscle activity was relatively low during this phase, the greater activation in the left side muscles indicated that the initiation of trunk lateral flexion to the left (all left muscles), extension (ES), and axial rotation to the right (EO and ES) occurred toward the end of this phase.

This descending windup phase is considered the coiling or loading of the upper body that enhances the distance (or time) the force acting on the racket during the acceleration phase. The longer distance (or time) results in higher racket velocity at ball impact. Bilateral differences in muscle activation were obvious in this phase except for the IO muscles. This suggests that while the other muscles are working on trunk lateral flexion and axial rotation, the IO muscles undergo eccentric contractions and play an important role in controlling the backward fall of the trunk. Because the trunk was flexing to the left, falling backward, and rotating to the right at the same time, it is logical that the left RA and EO (a contralateral trunk rotator) were more active than their right counterparts. Anderson[1] also found greater activation in the left EO as opposed to the right EO during the upward arm swing phase. However, only one of the eight subjects in Anderson's study showed activity greater than 50% max in the left EO during this phase. These figures are lower than the average EMG level in the left EO recorded in this study. It is very likely that the subjects in this study served more forcefully than the female subjects in Anderson's study.

All subjects left the ground while reaching up to strike the ball during the acceleration phase. All muscles showed moderate to high activity during this phase. The EMG activity of the RA, EO and IO muscles suggested that these muscles were responsible for the trunk flexion in this phase. The lateral trunk flexion to the left, as evidenced by the dropping of the left shoulder at impact, was assisted by the activity of the left RA.

In the acceleration phase, most abdominal muscles were more active in the topspin than in the other two types of serves (Figure 2) although the differences were statistically significant only in the right RA, left EO, and right IO. The moderate ES activity during this phase suggest that, instead of performing its primary function of trunk extension, the ES functions to stabilise the lumbar region during this phase.

All abdominal muscles showed drastic decreases in activity and the ES muscle became more active after the ball impact. Bilateral comparison of muscle activation during the follow-through phase suggested that the IO and ES muscles served to maintain the trunk posture in the antero-posterior direction. Because the EO is both an ipsilateral lateral flexor and a contralateral axial rotator, and the trunk was leaning to the left at the end of the acceleration phase, the greater activity of the right EO over the left EO suggested that the trunk was still rotating to the left and the right EO was involved in countering gravity during the follow-through phase.

In performing lifting tasks, McGill and Normal[14] asserted that even mild abdominal activity (co-contraction with trunk extensors) could cause noticeable increases in compressive loads on lumbar discs. Both bilateral and abdominal/low back co-activations among lower trunk muscles are unavoidable during trunk movement because these muscles function as units to maintain the balance between mobility and stability of the spinal column[15]. Extension of the trunk is more evident in tennis serve and overhead smash than in other strokes. Consequently, repetitive trunk extensions and co-activation of the lower trunk muscles associated with the tennis serve may place considerable stresses upon the various anatomical structures in the low back region. To provide further insight into this issue, estimation of the actual loads on the lumbar spine during different types of serves using the techniques of musculoskeletal modeling[16] is recommended for future studies.

The heavy involvement of lower trunk muscles in the tennis serve reinforces the importance of abdominal and low back exercises in the strength and rehabilitation programs designed for tennis players. Although kinematic characteristics of serving motion are not available in this study, it is obvious that most of the abdominal muscles and lower back muscles undergo eccentric contractions during the descending windup and follow-through phases, respectively, from qualitative observations. The moderate activities of these muscles during eccentric contractions suggest that eccentric training for the lower trunk muscles may be beneficial to tennis players.

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