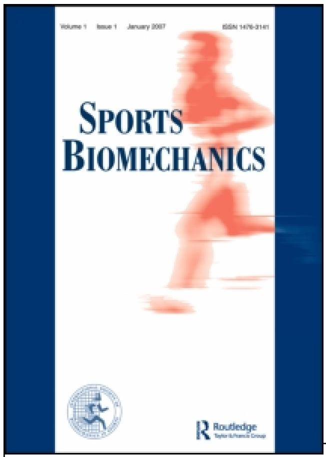

Sports Biomechanics
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t776628940

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To cite this Article: SEELEY, MATTHEW K., UHL, TIM L., MCCRORY, JEAN, MCGINN, PATRICIA, BEN KIBLER, W. and SHAPIRO, ROBERT (2008) 'A comparison of muscle activations during traditional and abbreviated tennis serves', Sports Biomechanics, 7:2, 248 — 259

To link to this article: DOI: 10.1080/14763140701841746
URL: http://dx.doi.org/10.1080/14763140701841746

Sports Biomechanics
May 2008; 7(2): 248–259

A comparison of muscle activations during traditional and abbreviated tennis serves

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Abstract
The abbreviated tennis serve is a relatively novel modification of the traditional serve that has been reported to provide performance advantages over the traditional technique. However, there are limited objective data regarding the benefits and biomechanics of the abbreviated serve; no data exist that describe shoulder muscle activations during the abbreviated serve. The purpose of this study was to compare muscle activations between the traditional and abbreviated serves. Electromyographic data were collected for the anterior and posterior deltoid, infraspinatus, middle trapezius, latissimus dorsi, serratus anterior, and pectoralis major. When muscle activations were compared during each serve phase, no significant differences were observed between the traditional and abbreviated tennis serve techniques, indicating that the traditional and abbreviated serves are similar regarding shoulder muscle activations. These results could have implications for performance of and injury related to the abbreviated versus traditional serve technique. Although the abbreviated serve has anecdotally been described as advantageous, the present data do not indicate any significant advantages or disadvantages in performing the abbreviated serve technique versus the traditional serve.

Keywords: *Athletics, biomechanics, electromyography, technique*

Introduction

As with other sport skills, the biomechanics of the tennis serve may affect performance or injury potential. It is especially important to consider serve biomechanics as new techniques are introduced. This ensures that novel techniques may potentially enhance performance, yet not create additional injury risk. The “abbreviated serve” was recently introduced as a modification to the traditional tennis serve (Van der Meer, 2001). The popularity of the abbreviated serve is increasing, as it has been advertised as a new and perhaps easier service technique (Van der Meer, 2001). The obvious difference between the abbreviated and traditional serves is that during the former, the racquet head does not drop vertically during the wind-up phase of the serve (Elliott, Fleisig, Nicholls, and Escamilla, 2003) (Figure 1). Suggested abbreviated serve benefits include a shortened cocking phase, improved ball toss consistency, and diminished racquet positioning error (Van der Meer, 2001). However,

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ISSN 1476-3141 print/ISSN 1752-6116 online
DOI: 10.1080/14763140701841746

it has been speculated that abbreviated serve performance may increase dominant shoulder injury risk, especially if the serve causes increased coronal-plane abduction of the humerus, in relation to the torso (Paley, Jobe, Pink, Kvitne, and El Attrache, 2000).

Despite increasing abbreviated serve popularity, biomechanical knowledge about the technique is limited. Upon visual inspection of the traditional and abbreviated serve, it is apparent that arm and racquet trajectories differ during the wind-up phase of the serve (Figure 1), yet little is known about the subtle differences between the two serves that may occur after the wind-up phase. The only known study to compare the mechanical characteristics of the traditional and abbreviated serve is that of Elliott et al. (2003). These authors compared various mechanical variables at maximal external rotation of the shoulder and throughout the rest of the traditional and abbreviated serve. Of all observed variables, only shoulder anterior force was significantly different between the traditional and abbreviated serve, and this was greater for the abbreviated serve. Elliott et al. (2003) did not compare muscle activations between the traditional and abbreviated serve, and it is not well understood how, or if, neuromuscular activations differ between the two service types.

The purpose of this study was to compare shoulder muscle activations during specific phases of the traditional and abbreviated serve using surface electromyography (EMG). As Elliott et al. (2003) reported similar mechanics for the traditional and abbreviated serve, it was hypothesized that EMG amplitudes for involved musculature would not differ significantly between the traditional and abbreviated serve. This study was performed to further elucidate plausible implications of adopting the traditional versus the abbreviated serve.

ABBREVIATED SERVE

TRADITIONAL SERVE

Figure 1. Photographs depicting the wind-up and cocking phases of the abbreviated and traditional tennis serves (chronological order is from left to right). The apparent difference between the serves occurs during the wind-up phase, as the racquet head does not drop below the waistline during the abbreviated serve.

Methods

Two groups of volunteers participated in this study. The first group ($n = 15$) performed the traditional serve (11 males and 4 females; age = 32 ± 13 years; height = 1.78 ± 0.85 m; mass = 75.9 ± 7.8 kg) and the second group ($n = 13$) performed the abbreviated serve (10 males and 3 females; age = 32 ± 15 years; height = 1.76 ± 0.66 m; mass = 74.2 ± 11.9 kg). Some exponents of the abbreviated serve did not utilize an "extreme" technique, but all met the abbreviated serve criterion: the racket head did not drop vertically during the wind-up phase of the serve (Elliott et al., 2003) (Figure 1). Three participants who demonstrated that they were proficient in both service techniques were included in both groups and performed the traditional and abbreviated serve within a single data collection session. Participants were required to be competing at the collegiate standard, or ranked at or above 4.5 by the United States Tennis Association. No participant had suffered an injury that prevented him or her from playing tennis within 6 months prior to data collection. All participants gave informed consent.

Each participant, ball, and racquet were instrumented with reflective markers (Figure 2) so that the instant of maximal external shoulder rotation, and ball and racquet trajectories could be determined and used to distinguish certain serve phases. Reflective markers were placed over the left and right anterior superior iliac spines, sacrum, left and right acromion processes, and seventh cervical vertebrae. Reflective marker triads were attached to the dominant upper arm and forearm. For calibration purposes, additional markers were placed

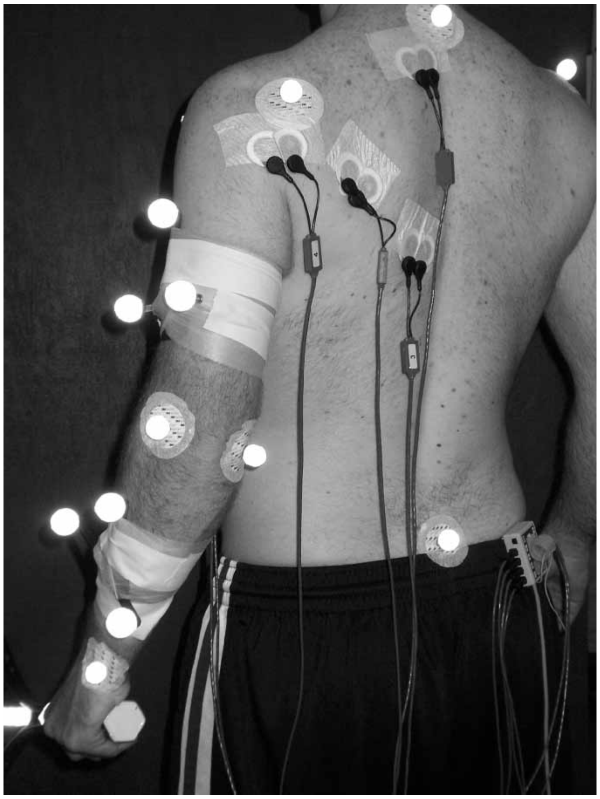

Figure 2. Photograph depicting reflective marker and electrode placement.

anterior and posterior to the shoulder joint centre, over the medial and lateral epicondyles of the humerus, and over the radial and ulnar styloids; these six markers indicated shoulder, elbow, and wrist joint centres. Six reflective markers were also placed on the racquet.

Imaging data were collected using high-speed videography (Motion Analysis Corporation, Santa Rosa, CA, USA). The motion capture volume was calibrated based on procedures that were described by the Motion Analysis Corporation and utilized the Direct Linear Transformation algorithm (Abdel-Aziz and Karara, 1971). Before participants began serving, the static anatomical calibration was collected to establish shoulder and elbow joint centres, and transformation matrices necessary to calculate segmental motion. Following this static anatomical calibration, the six markers indicating shoulder, elbow, and wrist joint centres were no longer needed and were removed. The participants then practised serving. This practice assured that reflective markers and electrodes were secure, and enabled participants to familiarize themselves to serving in the laboratory, while instrumented.

After the reflective markers were attached, surface electrodes were applied using standard procedures (Basmajian and DeLuca, 1985b) (Figure 2). Bipolar Ag/AgCl surface electrodes (Medicotest, Ambu, Glen Burnie, MD, USA) were placed over seven muscles: anterior and posterior deltoid, infraspinatus, middle trapezius, latissimus dorsi, serratus anterior, and pectoralis major. Electrode locations were determined using standard procedures (Zipp, 1982) and are described in Table I. A reference electrode was placed over the non-dominant acromion process. Electrodes were connected to active leads of a cable unit Myosystem 1400 EMG amplifier (Noraxon Inc., Scottsdale, AZ, USA). The total system amplification gain was set at 1000. After the electrodes were attached, 4-s maximal voluntary isometric contractions were performed for each muscle using standard manual muscle testing positions, allowing for normalization of EMG data (Basmajian & De Luca, 1985a; Kendall, McCreary, & Provance, 1993).

Although this was a laboratory experiment, effort was made to increase ecological validity by matching the laboratory set-up with competition conditions. A tape line, representing the service line, was applied to the laboratory floor in the centre of the motion capture volume. To represent the top of the tennis net, a tape line was attached to a circular collection net (2.75 m diameter), at a height of 0.91 m. Due to laboratory space constraints, the tape lines representing the service line and top of the tennis net were only 9.10 m apart, rather than the regulation 11.89 m. Participants were given uniform, explicit instructions related to serving in the laboratory. They were told to hit each serve: (1) flat (i.e. no topspin or backspin), (2) as though it was a first serve, and (3) at a competition standard. Regulation balls, partially

Table I. Directions used to place each surface electrode pair (Zipp, 1982).

Muscle	Location of electrode
Anterior deltoid	1/3 of distance from anterior acromion to deltoid tuberosity
Posterior deltoid	1/3 of distance from posterior acromion to deltoid tuberosity
Infraspinatus	1/2 of distance from medial to lateral scapular border, and 1/2 of distance from scapular spine and inferior scapular angle
Middle trapezius	1/2 of distance from root of scapular spine and the thoracic spinous process directly medial to the root of the scapular spine
Latissimus dorsi	4 cm inferior to inferior scapular angle, and 1/2 of distance from spinous process to lateral trunk
Serratus anterior	With humerus flexed to 90°, the bisection of: (1) a horizontal line at the vertical height of the inferior scapular angle and (2) the mid-axillary line
Pectoralis major	With humerus adbucted 90° and externally rotated to 90°, 1/3 of distance from the coracoid process to xiphoid process

Table II. Six divisions of the tennis serve that were considered during the present study (Morris *et al.*, 1989).

Phase	Description
Wind-up	From ball and racquet at rest to the instant that ball elevates to shoulder height
Early cocking	Cocking runs from ball at shoulder height to maximal shoulder external rotation; early cocking is the first 75% of this motion
Late cocking	The final 25% of cocking
Acceleration	From maximal shoulder external rotation to ball impact
Early follow-through	Follow-through runs from ball impact to the instant that the distal racquet is at its lowest vertical point; early follow-through is the first 25% of this motion
Late follow-through	The final 75% of follow-through

covered with reflective tape, were used for all serves. Only serves considered representative by the investigators and participants were analysed. Serves were determined to be representative if: (1) the ball struck the collection net near, but not below, the tape line representing the top of the tennis net, and (2) the participant described the serve as being representative of a competition first serve. A minimum of five good serves was required from each participant. Video and EMG data were collected synchronously at sampling rates of 240 and 960 Hz respectively.

Shoulder motion and ball and racquet trajectories were analysed first, so that serves could be divided into six phases, as described by Morris and colleagues (Morris, Jobe, Perry, Pink, and Healy, 1989) (Table II). ExpertVision software (Motion Analysis Corporation, Santa Rosa, CA, USA) was used to calculate spatial coordinates for all markers for all trials. Coordinate data were then smoothed using a fourth-order Butterworth digital filter with a cut-off frequency of 12 Hz (Fleisig, Nicholls, Elliott, and Escamilla, 2003). Effects of the racquet–ball impact were accounted for by padding the end of each trial with ten extrapolated data points, created via linear extrapolation (Smith, 1989). Sagittal-plane forearm orientation was used to estimate humeral internal–external rotation about the glenohumeral joint, as described by Feltner and Dapena (1986). Also, ball velocity was calculated using central differences for the three data points immediately following impact.

After serve phases had been identified, the EMG data were analysed. Data were high-pass filtered using a cut-off frequency of 20 Hz (Basmajian and DeLuca, 1985b). The common mode rejection ratio was greater than 100 dB. To calculate EMG amplitude, the root mean square amplitude for each muscle, during each serve phase, was determined using Datapac software (Run Technologies, Mission Viejo, CA, USA). Each root mean square value was then represented as a percentage of maximal voluntary isometric contraction amplitude. This procedure was performed for five serves and the percent amplitude for each muscle, during each phase, was averaged across five serves and compared statistically.

Repeated-measures analysis of variance with two within factors (phase and muscle) and one between factor (service group) was performed to compare EMG amplitudes between the two service techniques ($P = 0.05$). Bonferroni-Holm *post hoc* analyses were used to identify specific significant differences detected by the analysis of variance. Most importantly, EMG amplitudes were compared between the two service techniques for each muscle during each phase. The EMG amplitudes were also compared between phases and muscles. The data of only 27 participants (14 traditional and 13 abbreviated) underwent statistical analysis, as the EMG hardware malfunctioned during one data collection session.

Table III. EMG amplitude means and standard deviations (reported as a percentage of maximal voluntary isometric contraction) for the anterior shoulder muscles during each phase of the traditional (TR) and abbreviated (AB) tennis serves.

	Anterior deltoid		Pectoralis major		Serratus anterior	
Phase	TR	AB	TR	AB	TR	AB
Wind-up	14 ± 9	11 ± 7	15 ± 10	19 ± 13	17 ± 14	20 ± 12
Early cocking	30 ± 13	22 ± 11	22 ± 11	28 ± 15	28 ± 15	31 ± 16
Late cocking	80 ± 36	68 ± 32	93 ± 42	104 ± 72	65 ± 28	73 ± 39
Acceleration	47 ± 20	35 ± 21	68 ± 30	77 ± 38	56 ± 32	53 ± 25
Early follow-through	49 ± 28	42 ± 22	24 ± 17	46 ± 37	60 ± 38	72 ± 55
Late follow-through	40 ± 19	37 ± 15	22 ± 12	39 ± 30	50 ± 22	49 ± 31

Note: No significant differences were observed between the traditional and abbreviated serve when comparing each muscle during each phase.

Results

Mean EMG amplitudes, reported as a percentage of maximal voluntary isometric contraction, during each serve phase are presented in Tables III and IV. No significant between-group differences were detected when comparing each muscle during each serve phase. A muscle × group interaction was observed ($P = 0.048$), and Bonferroni-Holm *post hoc* comparisons revealed that for data pooled from all serve phases, mean infraspinatus amplitude was greater for the abbreviated serve group (Figure 3). Additionally, the middle trapezius, latissimus dorsi, and pectoralis major exhibited higher, but non-significant, EMG amplitudes for the abbreviated serve group (Figure 3).

A muscle × phase interaction was observed ($P < 0.001$), and Bonferroni-Holm *post hoc* comparisons showed that: (1) the middle trapezius was more active than the latissimus dorsi during early cocking; (2) during late cocking, the anterior deltoid was more active than the posterior deltoid and latissimus dorsi, the serratus anterior was more active than the latissimus dorsi, and the pectoralis major was more active than the posterior deltoid, middle trapezius, and latissimus dorsi; (3) during early follow-through, the middle trapezius was more active than the infraspinatus and latissimus dorsi; and (4) the posterior deltoid was

Table IV. EMG amplitude means and standard deviations (reported as a percentage of maximal voluntary contraction) for the posterior shoulder muscles during each phase of the traditional (TR) and abbreviated (AB) tennis serves.

	Posterior deltoid		Infraspinatus		Middle trapezius		Latissimus dorsi	
	TR	AB	TR	AB	TR	AB	TR	AB
WU	12 ± 6	8 ± 5	9 ± 9	12 ± 9	20 ± 11	25 ± 22	19 ± 19	23 ± 18
EC	26 ± 13	16 ± 13	19 ± 8	30 ± 14	39 ± 21	41 ± 25	20 ± 19	27 ± 20
LC	15 ± 13	13 ± 11	32 ± 19	57 ± 46	19 ± 11	38 ± 26	22 ± 19	28 ± 22
AC	81 ± 35	75 ± 36	28 ± 16	43 ± 26	54 ± 19	88 ± 66	83 ± 54	81 ± 49
EFT	67 ± 31	55 ± 31	20 ± 14	31 ± 17	53 ± 18	79 ± 59	28 ± 21	44 ± 34
LFT	57 ± 24	56 ± 33	36 ± 20	36 ± 21	41 ± 24	71 ± 55	23 ± 23	49 ± 65

Note: No significant differences were observed between the traditional and abbreviated serve when comparing each muscle during each phase. WU = wind-up; EC = early cocking; LC = late cocking; AC = acceleration; EFT = early follow-through; LFT = late follow-through.

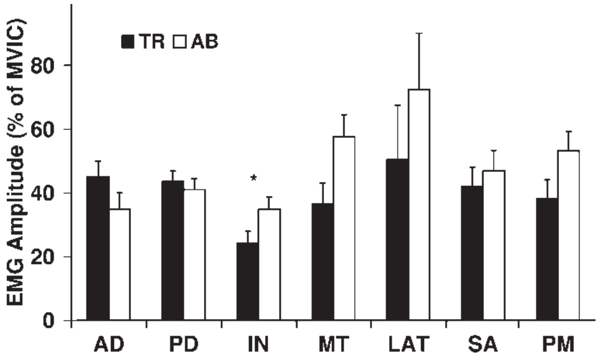

Figure 3. Mean electromyography (EMG) amplitudes, reported as a percentage of maximal voluntary isometric contraction (MVIC), for shoulder muscles during the entire abbreviated (AB) and traditional (TR) tennis serves. Considered muscles included the anterior deltoid (AD), posterior deltoid (PD), infraspinatus (IN), middle trapezius (MT), latissimus dorsi (LAT), serratus anterior (SA), and pectoralis major (PM). The asterisk indicates a significant difference between the traditional and abbreviated serve.

more active than the infraspinatus during early and late follow-through. These data, pooled from both service techniques, are presented in Tables V and VI.

Other variables of interest were calculated as a result of EMG analyses that were the primary focus of this study. Maximal external shoulder rotation angles, analysed to distinguish the late cocking and early follow-through phases, were not significantly different between the traditional (137 ± 12°) and abbreviated serve (140 ± 15°). There was no significant difference in ball velocity between the traditional (43.1 ± 8.1 m/s) and abbreviated serve (41.2 ± 5.8 m/s). Additionally, there were no significant differences between the traditional and abbreviated serve for the absolute duration of each serve phase (Figure 4).

Discussion and implications

The abbreviated serve is a recent modification to the traditional serve and has been described as a more effective serve technique (Van der Meer, 2001), yet the abbreviated biomechanics are not completely understood. The purpose of this study was to determine if differences in muscle activations exist between the abbreviated and traditional serve. The present results supported the hypotheses and indicated that shoulder muscle activations were quite similar during the abbreviated and traditional serve. In comparing each muscle during each serve phase, no significant differences were noted between the abbreviated and traditional serve.

Table V. EMG amplitude means and standard deviations (reported as a percentage of maximal voluntary contraction) for the anterior shoulder muscles during each phase of the tennis serve.

Phase	Anterior deltoid	Pectoralis major	Serratus anterior
Wind-up	12 ± 2	19 ± 4	18 ± 4
Early cocking	30 ± 4	23 ± 5	24 ± 5
Late cocking	79 ± 5	87 ± 13	60 ± 8
Acceleration	40 ± 5	79 ± 12	50 ± 7
Early follow-through	47 ± 7	47 ± 12	67 ± 14
Late follow-Through	37 ± 5	41 ± 10	48 ± 7

Note: Data were pooled for the two service techniques.

Table VI. EMG amplitude means and standard deviations (reported as a percentage of maximal voluntary contraction) for the posterior shoulder muscles during each phase of the tennis serve.

Phase	Posterior deltoid	Infraspinatus	Middle trapezius	Latissimus dorsi
Wind-up	12 ± 2	14 ± 1	26 ± 6	18 ± 5
Early cocking	25 ± 3	31 ± 4	47 ± 9	20 ± 4
Late cocking	24 ± 4	59 ± 14	35 ± 7	24 ± 6
Acceleration	79 ± 1	34 ± 4	66 ± 13	76 ± 12
Early follow-though	57 ± 6	25 ± 3	68 ± 8	35 ± 8
Late follow-through	67 ± 6	41 ± 5	52 ± 19	50 ± 19

Note: Data were pooled for the two service techniques.

Data were also pooled from across all serve phases, offering a view of activations for each muscle across the entire serve. For these pooled data, mean infraspinatus amplitude was significantly greater for the abbreviated serve group (Figure 3). This difference was attributed to the one apparent kinematic difference between the abbreviated and traditional technique (a more elevated humerus) during the early serve phases (Figure 1). The middle trapezius and pectoralis major also exhibited increased, but non-significant, activations for the abbreviated group (Figure 3), for data pooled from across all serve phases. These increased means were also thought to be related to the abbreviated serve method of keeping the humerus more elevated during the early phases of the serve.

A significant muscle × phase interaction indicated that muscle amplitudes differed between serve phases, yet these differences were independent of service technique. This was not surprising, as it was expected that muscle activations would vary between serve phases. These expectations were based on previously reported EMG data describing overhead activities that indicated muscle activations differ between phases during the traditional serve (Glousman, 1993; Ryu, McCorkick, Jobe, Moynes, and Antonelli, 1988). The present data are in line with the conclusions of Glousman (1993) and Ryu et al. (1988) in that the serratus anterior is most active during late cocking, and the latissimus dorsi is most active during acceleration. It should be re-emphasized that this muscle × phase interaction was independent of service technique, and muscle activations differed similarly between serve phases during the abbreviated and traditional serve.

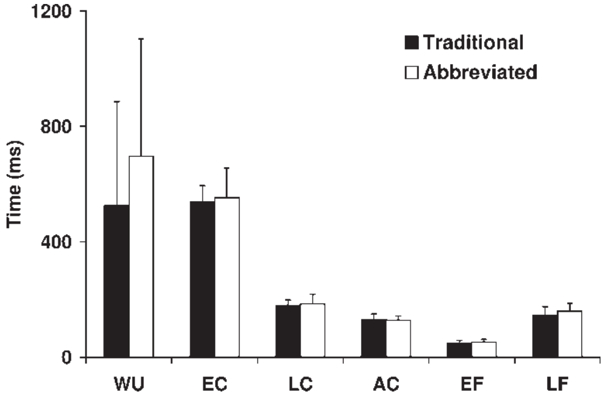

Figure 4. Means and standard deviations for duration of each phase during the traditional and abbreviated serves (WU = wind-up; EC = early cocking; LC = late cocking; AC = acceleration; EF = early follow-through; LF = late follow-through). No differences were observed between the traditional and abbreviated service techniques for any serve phase.

The present results corroborate results reported by Elliott et al. (2003), who compared the kinetics and kinematics of the traditional and abbreviated serve during the 2000 Olympics, and found no significant biomechanical differences between the traditional and abbreviated serve. As no kinetic or kinematic differences were observed between the traditional and abbreviated serve, similarities in muscle activations were not surprising. Also, the present values describing maximal shoulder external rotation and ball velocity are less than, but comparable to, values reported by Elliott et al. (2003). This was expected, as ours was a laboratory study involving athletes competing at standards below the Olympic standard observed by Elliott et al. (2003). As similar mechanics were reported for the traditional and abbreviated serve, similar ball velocities and serve phase durations were expected, and the present data confirmed these expectations. This lack of a between-group difference for absolute serve phase duration suggests that timing of the ball toss and other related timing actions throughout the stroke are not altered by the technique adopted.

Several coaching applications may be drawn from the present study. Based on the observed muscle activations, the abbreviated serve does not appear to place additional muscular demand on the upper extremities of those who perform the task skillfully. Therefore, the abbreviated serve appears to be a viable method for hitting a tennis serve. However, based upon the present ball velocity data, the abbreviated serve does not appear to generate more serving force, or be more effective in achieving maximal external shoulder rotation during the cocking phase of the serve. Therefore, the abbreviated serve should not be advertised as a superior serve technique. Additionally, it appears that the abbreviated serve may require greater muscle activations for muscles that actively position the arm in maximal external rotation. Additional conditioning of the humeral external rotation muscles may be required for players using the abbreviated serve. Finally, it should be remembered that the participants in the present study were skilled and healthy tennis players who are capable of developing high compensatory variability. The present data may not be directly applicable to younger or unskilled players.

This study had some limitations. Crosstalk may have affected amplitudes for muscles in close proximity. This was minimized in two ways: (1) accepted recommendations were followed when determining electrode placement, and (2) electrode placement was confirmed by oscilloscope activity during manual muscle tests (Ryu et al., 1988). Surface EMG has been used to study similar muscles during similar dynamic activities (Bankoff, Fonseca Neto, Zago, and Moraes, 2006; Hirashima, Kadota, Sakurai, Kudo, and Ohtsuki, 2002; Myers et al., 2005). Also, this study is limited by the difficulty of representing competition serves in a laboratory setting, including the objective evaluation of serve accuracy: we were unable to determine if the serve would have landed in the service court. This limitation was minimized in three ways: (1) the participants were given explicit, uniform instruction about laboratory serves that emphasized the importance of a representative, first, flat serve; (2) the participants, all of whom were experienced tennis players, rated all analysed serves as representative; and (3) the laboratory set-up conformed to tennis court dimensions as much as possible.

Conclusion

The abbreviated serve is a modification of the traditional serve that some believe offers certain performance advantages over the traditional technique (Van der Meer, 2001), yet the biomechanics and purported benefits of the abbreviated serve are not well understood. Prior to the present study, muscle activations during the abbreviated serve were unknown. The purpose of this study was to compare shoulder muscle activations during each serve phase, between the traditional and abbreviated serve. When comparing muscle activations during each serve phase, no significant differences between the traditional and abbreviated serve were found. Both service techniques require comparable muscular strength during each serve phase, and are comparable in performance potential and injury risk for healthy athletes performing the serve. When comparing muscle activations across the entire serve, one noteworthy difference was observed: mean infraspinatus EMG amplitude was greater for the abbreviated serve. This indicates that the abbreviated serve may be more problematic for individuals suffering from weak or injured rotator cuff muscles. Consequently, athletes who adopt the abbreviated serve and suffer from rotator cuff pathologies should be especially diligent in rehabilitation protocols and cautious in returning to full play. However, speaking generally, previous (Elliott et al., 2003) and present results indicate that the traditional and abbreviated serve are biomechanically similar.

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Appendix

Sum of squared error, degrees of freedom, mean squared error, *F* ratio, and alpha level (*P*) describing the significant interaction between the main effects of muscle and serve phase.

Interaction	Sum of squares	Degrees of freedom	Mean square	*F* ratio	*P*
Muscle × phase	258018	30	8601	8.549	< 0.001

Selected results from Bonferroni-Holm *post hoc* comparisons of mean electromyography amplitudes during each serve phase; only alpha levels (*P*) that were less than 0.05 are presented here. Asterisks indicate comparisons that were significantly different after the Bonferroni-Holm correction (AD = anterior deltoid; PD = posterior deltoid; INF = infraspinatus; MT = middle trapezius; LAT = latissimus dorsi; SA = serratus anterior; PM = pectoralis major).

Phase	Muscles		*P*
Wind-up			
	PD	MT	0.040
	LAT	MT	0.002
Late cocking			
	AD	PD	< 0.001*
	AD	MT	0.001
	AD	LAT	< 0.001*
	PD	INF	0.046
	PD	SA	0.006
	PD	PM	< 0.001*
	INF	LAT	0.031
	MT	LAT	0.017
	MT	SA	0.007
	MT	PM	< 0.001*
	LAT	SA	< 0.001*
	LAT	PM	< 0.001*
	SA	PM	0.010
Early follow-through			
	AD	INF	0.008
	PD	INF	< 0.001*
	PD	LAT	0.017
	INF	MT	< 0.001*
	INF	SA	0.011
	MT	LAT	< 0.001*
	MT	PM	0.044

Appendix – *continued*

Phase	Muscles		*P*
Early cocking			
	PD	MT	0.044
	MT	LAT	$< 0.001^*$
	MT	SA	0.022
	MT	PM	0.004
Acceleration			
	AD	PD	0.002
	AD	LAT	0.025
	AD	PM	0.014
	PD	INF	0.002
	PD	SA	0.027
	INF	MT	0.019
	INF	LAT	0.005
	INF	SA	0.048
	INF	PM	0.001
	SA	PM	0.022
Late follow-through			
	AD	PD	0.003
	PD	INF	$< 0.001^*$
	PD	SA	0.015
	PD	PM	0.002