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Research article

Upper Extremity Muscle Activation during Drive Volley and Groundstroke for Two-Handed Backhand of Female Tennis Players

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Abstract
Drive volley is one of the essential backhand stroke technique trends seen in recent women's tennis competitions. Although movements of the drive volley and groundstroke are similar, activation of the internal muscles vary due to different incoming ball conditions. Most previous studies only focused on the groundstroke, however. The current study investigates the different muscle activation patterns in the upper extremity muscle during the two-handed backhand drive volley as well as the groundstroke for female tennis players. Ten elite female tennis players were measured in the muscle activation of the flexor carpi radialis (FCR), extensor carpi radialis (ECR), biceps brachii (BB), and triceps brachii (TB) from both upper extremities. Racket-head speed at impact, swing duration of each phase, and racket-head average velocity in both strokes were also recorded. Significant differences were found between the drive volley and groundstroke in the velocity profile of racket tip, swing duration of each phase (preparation, early follow-through, and late follow-through), activation patterns of upper extremity muscles, and flexor/ extensor ratios of wrist and elbow in both upper extremities. Different racket trajectory strategies were also observed between the two strokes, with greater horizontal racket velocity recorded in the groundstroke but greater vertical velocity in the drive volley. ECR and TB muscle activation during the drive volley preparation phase was greater than the groundstroke when completing a quicker backswing. In the early acceleration phase, the greater FCR leading arm activation in the drive volley assisted wrist stabilization in preparation for impact. In the late follow-through phase, less TB leading arm activity and higher ECR trailing arm activity in the drive volley showed more forward compression movement in racket contact with the ball. As it is essential for the drive volley to complete a quicker backswing and to increase shot efficiency at the end of the forward movement, coaches should consider the two strokes' muscle activation and technique differences to enhance specific techniques and fitness training programs.

Key words: EMG, leading arm, trailing arm, racket speed.

Introduction

The backhand groundstroke provides one of the cornerstones of high-performance play in tennis, where it accounted for approximately 24% of rally balls during the 2012-2015 Australian Opens, for example (Elliott et al., 2018). The two-handed backhand groundstroke increases versatility and consistency compared with the one-handed stroke, and is thus preferred by more than 90% of the current top 100 female world-ranked players. Furthermore, the drive volley is preferred over the conventional volley, in being an essential offensive weapon that connects the backcourt and frontcourt in high-performance women's play (Antoun, 2007; Rineberg, 2004; Bollettieri, 2015). Both the two-handed backhand groundstroke and drive volley are therefore important skills for an all-court game.

Most studies on the backhand in the last decade, however, have only focused on the groundstroke (e.g., Stępień et al., 2011; Landlinger et al., 2012; Loushin et al., 2022). As there has been limited technical research data on the drive volley, advice for coaches on the role the two upper extremities play in this stroke is not based extensively on science. Analysis of the drive volley in this context is therefore warranted.

Specifically, in the swing motion, the mechanics drive volley is similar to the groundstroke, but drive volleys demand more downward-upward power (Rive and Williams, 2011). Furthermore, the groundstroke is learned before the more difficult drive volley in most tennis training, and coaches often use the drive volley to demonstrate how to enhance control ability of the accurate grasping hitting zone, and sensitivity to the detail of ball contact (Mouratoglou, 2022). For example, Rive and Williams (2011) mentioned that for skilled players, the drive volley was one of the drills used in tactical training to improve the acceleration of the racket-head in the backhand stroke. Consequently, understanding higher levels of the drive volley and the similarity/dissimilarity of muscle activation patterns between the drive volley and groundstroke of the two-handed backhand is critical to skill transfer and precise execution.

The arm and wrist serve an essential role in both strokes as the last link between players and equipment (racket and ball) at ball contact (Elliott, 2006; Roetert and Kovacs, 2019). While the mechanics of the two are similar, strokes where the coming ball is hit before the bounce may require more contact force at impact to be successful (Rive and Williams, 2011). Electromyographic (EMG) can provide underlying muscle information, but in the last two decades, most studies on varying muscle upper extremity activation in the backhand groundstroke emphasized the leading (dominant) arm (e.g., Chow et al., 1999; Hatch et al., 2006; Wei et al., 2006). Previous kinematics research, however, has confirmed the trailing (non-dominant) arm contributed to the racket's horizontal velocity (Stępień et al., 2011) as well as the effects of different grips on the wrist and elbow (Busuttil et al., 2020).

Prior research has also suggested different factors that can influence upper extremities muscle activation

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transmission of impact loads, including technical, ball size, ball weight, ball spin, racket weight, and grip form (e.g., Chow et al., 2007; Eckerle, 2010; Rogowski et al., 2009, 2011; Alizadehkhaiyat et al., 2007). These studies proposed that muscle activation varies in different impact conditions, where the drive volley, for example, may need a high muscle activation level in certain muscles to overcome the force of impact. When Huang et al. (2005) calculated the flexor/ extensor EMG ratio to assess intermuscular coordination in the double-handed backhand stroke, they found that roles the muscle agonist-antagonist played in both upper limbs were different. However, there is no current EMG data for the drive volley. Consequently, understanding the muscle activation levels of the upper extremities in the drive volley and groundstroke of the two-handed backhand can contribute to understanding of how skill transfer may occur and the precise technical execution of these strokes. Such findings would provide better insights on the different muscle activation patterns between both strokes, and thus warrants further investigation.

This study aims to investigate the muscle activation patterns of the upper extremities during two-handed backhand drive volley and backhand groundstroke in elite female tennis players. While both strokes have similar movements but respond to the coming ball differently, we assume that the muscle activation of both strokes will be different; especially close to impact, the muscle activation level of the drive volley might be greater than that of groundstroke. Results from this study can provide a useful guideline of how inherent skill transfers may occur between these strokes. Furthermore, specific knowledge and strategies on muscle activation from the two upper extremities may be used to enhance physical training programs and technique coaching.

Methods

Participants

Study participants include ten skilled right-hand dominant female tennis players (age 19.6 ± 5.3 years; height 1.68 ± 0.04 m; mass 61.5 ± 5.4 kg; and tennis experience 9.1 ± 3.3 years), who were ranked in the top 32 players in Taiwan (level of the International Tennis Number is about ITN 2). They all used a two-handed backhand and were familiar with the two-handed backhand drive volley technique. All subjects used the continental grip for the right hand. For the left hand, seven subjects used the eastern grip, and three used with semi-eastern grip. To be included in the study, participants were required to have no sustained injuries to their shoulders, elbows, wrists, or knees in the preceding three months. The Institutional Review Board approved this study, which was conducted by Fu Jen Catholic University in Taiwan.

Experimental session and procedures

The experimental process for this study was explained to the participants, after which they signed a consent form. In preparation for the experiment, the skin of participants' upper extremities was cleaned with alcohol before EMG electrodes were attached using sport foam and sticky tape. The muscle activation signals of the flexor carpi radialis (FCR), extensor carpi radialis (ECR), biceps brachii (BB), and triceps brachii (TB) were recorded in both upper extremities with the Delsys-16 EMG system (Delsys Inc., Natick, MA, USA) at 2000 Hz. All of the sensor muscle placements were based on procedures outlined in Criswell (2010). Racket head speed was recorded using a 3-D infrared motion analysis system (Motion Analysis Corporation, USA, 200 Hz). Participants all used the same racket (grip $4_{1/4}$ inches and mass 300 g; Pure Drive; Babolat Play, France, 2014) with a reflective marker attached to the tip to record racket kinematics. The formal experiment was initiated after participants were given time to familiarize themselves with the process and the environment, particularly the racket that was similar in mass and grip size to that typically used.

A ball machine set at the center baseline mark was used to deliver balls at 36 km/hr to an area of 1.2 × 1.2 m^2 positioned on the opposite baseline (Figure 1A). Balls were fed to the backhand side with a projection angle passing over the net at >3 m for the drive volley and <1.5 m for the groundstroke. Players were instructed to hit their groundstroke from the baseline down the line with the backhand stroke, while hitting the drive volley between the baseline and service line with the power to the same target area. A successful shot was recorded when the ball landed within the prescribed 3 × 2 m^2 target area (Figure 1B). All participants were required to make five successful groundstrokes before recording five successful drive volleys. Upon completing the stroke performance tests and a rest period, participants then performed two maximal voluntary isometric contractions (MVIC) of 5 s duration, with a rest interval of 1 minute between efforts, as described by Konrad (2005) (Table 1).

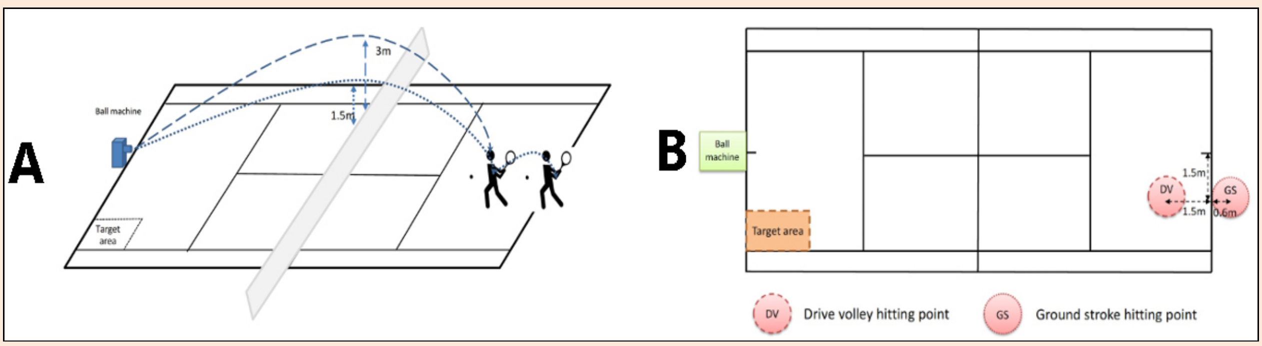

Figure 1. A. Experiment setup for both backhand drives. (Side view), B. Experiment setup for both backhand drives. (Top view).

Table 1. Procedure to perform the maximal voluntary isometric contraction (MVIC) of each muscle (Konrad, 2005).

Muscle group	Description	
Biceps brachii (BB)	Seated on a chair and fastened securely at the elbow and trunk, the upperarm was placed on the table with the forearm about 90-110°, the hand in a fist position and supinated. Manual resistance applied forward against the distal forearm.	
Triceps brachii (TB)	Seated on a chair and fastened securely at the elbow and trunk, the upperarm was placed on the table with the forearm about 90-110°, the hand in a fist position and supinated. Manual resistance applied backward against the distal forearm.	
Flexor carpi radialis (FCR)	Seated on a chair and fastened securely at the elbow and trunk with the forearm horizontal and supinated, the hand in a fist. Manual resistance was applied downward against the hand.	
Extensor carpi radialis (ECR)	Seated on a chair and fastened securely at the elbow and trunk with the forearm horizontal and pronated, the hand in a fist. Manual resistance was applied downward against the hand.	

The grey arrows represent the direction of resistance.

Table 2. Kinematic parameters of the racket tip

Kinematics of the racket tip		Drive volley (Mean ± SD)	Groundstroke (Mean ± SD)	p-value	Effect size
Velocity at impact (m/s)	Horizontal velocity	21.79 ± 1.90	24.63 ± 2.44	.00*	1.30
	Vertical velocity	13.05 ± 1.52	10.91 ± 1.55	.00*	1.39
	Resultant velocity	25.46 ± 1.87	26.99 ± 2.42	.01*	0.71
Swing duration of each phase (s)	Preparation	0.11 ± 0.03	0.15 ± 0.04	.01*	1.07
	Early Acceleration	0.03 ± 0.01	0.02 ± 0.01	.17	0.33
	Late Acceleration	0.01 ± 0.00	0.01 ± 0.00	.17	0.32
	Early Follow-through	0.01 ± 0.00	0.01 ± 0.00	.04*	1.00
	Late Follow-through	0.04 ± 0.01	0.03 ± 0.01	.04*	0.72
Average Velocity (m/s)	Preparation	1.98 ± 0.70	1.95 ± 0.59	.82	0.05
	Early Acceleration	6.01 ± 2.09	6.59 ± 2.04	.16	0.28
	Late Acceleration	15.97 ± 2.91	17.39 ± 2.33	.03*	0.54
	Early Follow-through	15.19 ± 1.89	16.71 ± 2.02	.01*	0.78
	Late Follow-through	6.61 ± 1.34	7.91 ± 1.99	.03*	0.77

* $p < 0.05$

Data analysis

In data analysis, phases of the backhand stroke were identified from the kinematic parameters of the marker on the racket tip, including preparation, early and late acceleration phases, and early and late follow-through phases. The preparation phase was defined from when a player assumed the preparatory posture to the end of the backswing. The end of the backswing was defined from when the horizontal velocity of the racket shifted from negative to positive. The acceleration phase was then measured from the end of the backswing to ball impact. Early acceleration was found in the first 75% of this phase, and the last 25% of the phase showed late acceleration. Finally, the follow-through phase was defined from impact until completion of the swing, when the racket had minimum resultant forward velocity. The first 25% and the following 75% of this phase were defined as the early and late follow-through, respectively (Morris et al., 1989; Giangarra et al., 1993). The kinematic parameters provided racket tip velocity for the resultant horizontal and vertical velocity at impact, time duration, and average velocity in each phase.

All data were saved and analyzed using customized software (EMGworks 4.1.7 DelSys Inc.). Raw EMG signals collected during the two backhands and the different MVICs were filtered (Butterworth order 4, bandpass 20–500 Hz) before root mean square (RMS) values were calculated (moving window 20 ms) (Morris et al., 1989). IMVC values were calculated from the EMG signals collected during MVIC (Figure 2). The normalized activation values were determined from EMG RMS signals recorded during both backhands, divided by the IMVC of each muscle, expressed as a percentage of the activation level recorded. The normalized activation value showed the mean value was normalized by the IMVC. The flexors/ extensor ratio of normalized activation at wrist and elbow joints for both two-handed backhand strokes were calculated for each phase.

The data were averaged for the three fastest racket-head speed trials from the five successful drive volleys and five ground strokes of each participant. All study data were expressed as mean ± SD. Paired sample t-tests were performed to compare drive volley and groundstroke backhand data, including muscle activation (FCR, ECR, BB, and TB), ratio of flexor/ extensor of the wrist and elbow joints, and kinematic parameters of the racket-head. All analyses were performed in SPSS version 20.0 (SPSS, Inc., Chicago, IL) with a significance level of $P < 0.05$.

Results

The kinematics parameters of the racket tip

Results in Table 2 show the kinematic parameters of the racket tip, where the resultant and horizontal velocities for the groundstroke were significantly higher at impact (26.99 ± 2.42 and 24.63 ± 2.44 m/s) than the drive volley (25.46 ± 1.87 and 21.79 ± 1.90 m/s). However, vertical velocity in the drive volley (13.05 ± 1.53 m/s) was significantly higher than the groundstroke (10.91 ± 1.55 m/s). This means the groundstroke required higher resultant and horizontal velocities, whereas the drive volley required higher vertical velocity. In time duration of the specific swing phase, the drive volley took less time than the groundstroke in the preparation phase (0.11 ± 0.03 and 0.15 ± 0.04 s), but had a longer follow-through phase than the groundstroke (0.05 ± 0.01 and 0.04 ± 0.01s). In terms of average velocity, the groundstroke was faster than the drive volley in late acceleration and follow-through phases.

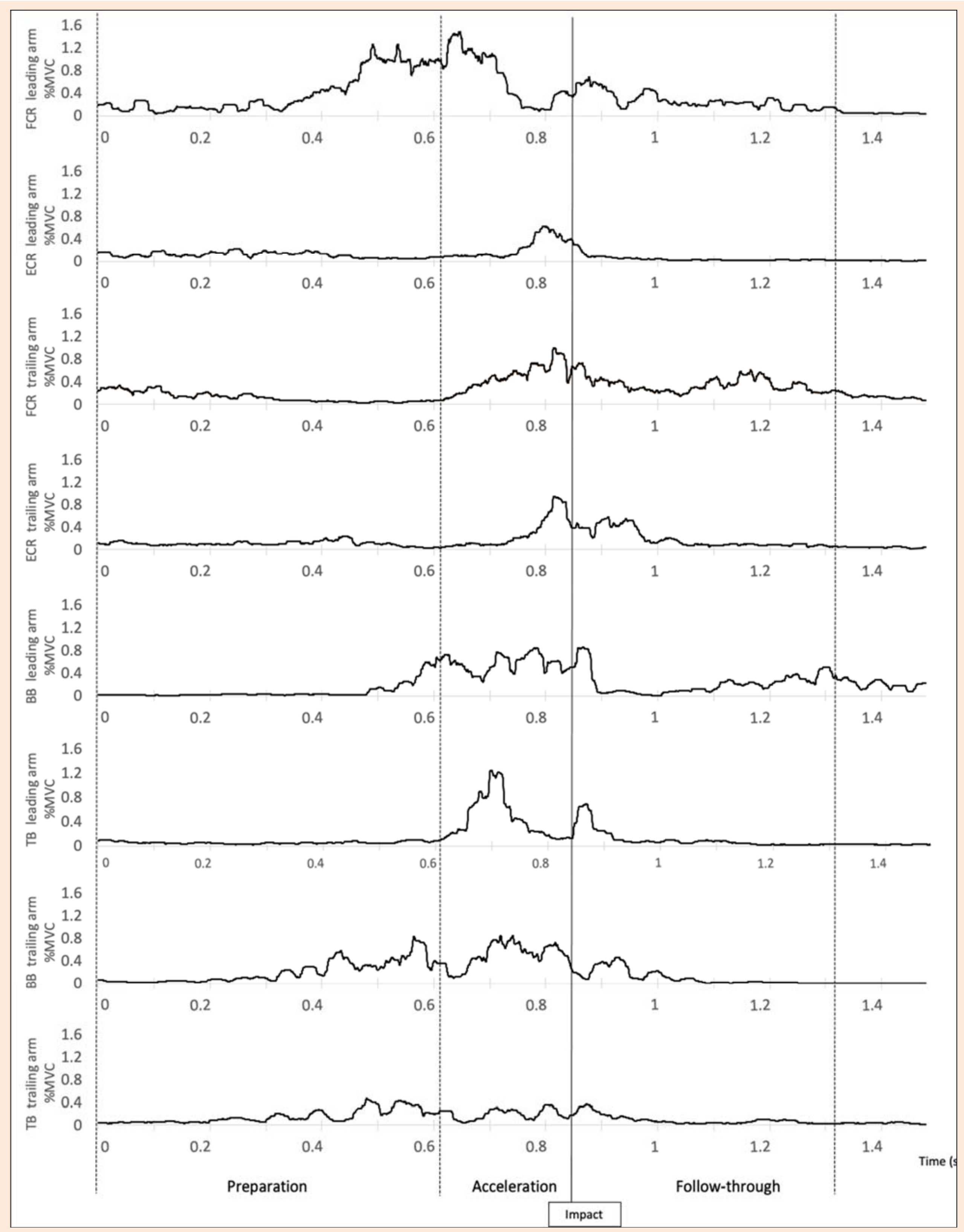

Figure 2. Normalized activation (%MVC) of each muscle in drive volley for one subject.

Table 3. Normalized activation of leading arm for upper extremity muscles in two-handed backhand strokes (% MVC).

Leading arm		Drive volley (Mean ± SD)	Groundstroke (Mean ± SD)	p-value	Effect size
Preparation	FCR	18.00 ± 4.54	16.06 ± 5.72	.10	0.38
	ECR	12.09 ± 5.16	11.21 ± 4.87	.28	0.18
	BB	3.98 ± 2.04	3.94 ± 1.52	.93	0.02
	TB	5.54 ± 2.84	5.68 ± 3.37	.84	0.04
Early Acceleration	FCR	52.50 ± 20.52	40.39 ± 13.91	.02*	0.69
	ECR	44.70 ± 31.22	44.50 ± 29.88	.97	0.01
	BB	20.33 ± 16.05	28.98 ± 19.43	.05	0.49
	TB	24.56 ± 13.22	31.52 ± 26.96	.22	0.33
Late Acceleration	FCR	55.90 ± 35.49	48.12 ± 21.30	.15	0.27
	ECR	91.17 ± 36.89	94.66 ± 32.42	.53	0.10
	BB	52.19 ± 18.74	52.14 ± 21.03	.99	0.00
	TB	32.06 ± 13.09	31.30 ± 24.34	.88	0.04
Early Follow-through	FCR	22.53 ± 5.84	19.98 ± 7.91	.14	0.37
	ECR	32.62 ± 17.12	28.86 ± 17.19	.44	0.22
	BB	22.57 ± 13.46	23.49 ± 15.94	.62	0.06
	TB	12.18 ± 3.93	16.95 ± 19.11	.38	0.35
Late Follow-through	FCR	9.69 ± 5.49	10.93 ± 6.35	.24	0.21
	ECR	16.39 ± 12.16	14.33 ± 11.29	.17	0.18
	BB	18.87 ± 8.81	18.67 ± 9.19	.94	0.02
	FCR	18.00 ± 4.54	16.06 ± 5.72	.10	0.38

* $p < 0.05$

Muscle activation of upper extremity

Results of Table 3 show the normalized muscle activation in the leading arm for each phase. Normalized muscle activation of the drive volley FCR (52.50 ± 20.52 %) in the leading arm was significantly higher than the groundstroke (40.39 ± 13.91 %) during the early acceleration phase. In addition, during the late follow-through phase, the normalized activation of TB in the leading arm was significantly less during the drive volley (3.95 ± 1.96 %) than groundstroke (5.58 ± 2.44 %). No significant differences in muscle activation between drive volley and groundstroke were observed during the preparation, late acceleration and early follow-through phases, however. This implies the leading arm required more FCR participation during the acceleration phase for the drive volley and more involvement of the TB during the late follow-through phase for the groundstroke.

Table 4 shows the normalized muscle activation in the trailing arm for each phase. In the trailing arm, the normalized activations of ECR and TB during the preparation phase were significantly higher for the drive volley (23.70 ± 8.56 and 8.89 ± 5.00 %) compared with the groundstroke (20.00 ± 10.30 and 7.20 ± 3.70 %). Moreover, in the late follow-through phase, the normalized activation of ECR was significantly higher for the drive volley (11.24 ± 8.33 %) than groundstroke (7.79 ± 4.80 %). No significant differences were observed during the entire acceleration and early follow-through phases, however. This shows that the trailing arm required more activation of ECR and TB muscles activated during the preparation phase for a drive volley, confirming that ECR muscles play a vital role during the late follow-through phase.

Table 4. Normalized activation of trailing arm for upper extremity muscles in two-handed backhand strokes (% MVC).

Trailing arm		Drive volley (Mean ± SD)	Groundstroke (Mean ± SD)	p-value	Effect size
Preparation	FCR	12.32 ± 4.88	12.84 ± 6.98	.69	0.09
	ECR	23.70 ± 8.56	20.00 ± 10.30	**.05***	0.39
	BB	8.40 ± 4.50	8.11 ± 5.49	.70	0.06
	TB	8.89 ± 5.00	7.02 ± 3.70	**.04***	0.43
Early Acceleration	FCR	30.50 ± 11.13	34.86 ± 13.56	.23	0.35
	ECR	43.70 ± 24.25	35.74 ± 18.69	.15	0.37
	BB	33.09 ± 17.85	34.81 ± 19.35	.62	0.09
	TB	30.92 ± 31.92	24.53 ± 15.33	.29	0.26
Late Acceleration	FCR	70.97 ± 14.81	81.99 ± 30.55	.16	0.46
	ECR	66.01 ± 33.60	68.34 ± 39.11	.58	0.06
	BB	40.19 ± 22.80	43.39 ± 22.65	.37	0.14
	TB	29.81 ± 12.82	39.01 ± 30.90	.26	0.39
Early Follow-through	FCR	26.36 ± 8.16	28.01 ± 11.68	.52	0.16
	ECR	34.48 ± 14.84	32.83 ± 16.17	.51	0.11
	BB	10.37 ± 5.21	12.48 ± 7.98	.21	0.31
	TB	25.43 ± 26.66	22.61 ± 8.05	.71	0.14
Late Follow-through	FCR	17.57 ± 9.10	18.94 ± 9.87	.39	0.14
	ECR	11.24 ± 8.33	7.79 ± 4.80	**.04***	0.51
	BB	2.75 ± 1.80	2.07 ± 0.85	.35	0.48
	TB	10.75 ± 4.53	11.74 ± 7.04	.51	0.17

* $p < .05$

Table 5. Flexor/ extensor ratio of normalized activation for both two-handed backhand strokes.

Flexor/ Extensor Ratio			Drive volley (Mean ± SD)	Groundstroke (Mean ± SD)	p-value	Effect size
Preparation	Wrist joint	Leading arm	1.65 ± 0.49	1.54 ± 0.43	.51	0.22
		Trailing arm	0.59 ± 0.35	0.74 ± 0.44	**.01***	0.38
	Elbow joint	Leading arm	1.05 ± 0.94	0.96 ± 0.63	.56	0.11
		Trailing arm	1.07 ± 0.54	1.29 ± 0.85	.10	0.31
Early Acceleration	Wrist joint	Leading arm	2.10 ± 1.94	1.45 ± 1.24	.06	0.40
		Trailing arm	1.01 ± 0.87	1.25 ± 0.98	**.03***	0.25
	Elbow joint	Leading arm	0.82 ± 0.43	1.23 ± 0.82	.14	0.62
		Trailing arm	1.92 ± 1.32	1.92 ± 1.23	.98	0.00
Late Acceleration	Wrist joint	Leading arm	0.65 ± 0.33	0.52 ± 0.15	.12	0.50
		Trailing arm	1.29 ± 0.62	1.38 ± 0.51	.47	0.16
	Elbow joint	Leading arm	1.94 ± 1.10	1.94 ± 1.09	.99	0.01
		Trailing arm	1.76 ± 1.46	1.81 ± 1.76	.74	0.03
Early Follow-through	Wrist joint	Leading arm	1.00 ± 0.96	0.90 ± 0.58	.68	0.12
		Trailing arm	0.88 ± 0.38	0.94 ± 0.35	.34	0.18
	Elbow joint	Leading arm	2.12 ± 1.63	1.95 ± 1.23	.49	0.12
		Trailing arm	0.62 ± 0.45	0.62 ± 0.47	.98	0.00
Late Follow-through	Wrist joint	Leading arm	1.01 ± 1.04	1.26 ± 1.18	.10	0.22
		Trailing arm	2.18 ± 1.65	2.88 ± 1.52	.09	0.44
	Elbow joint	Leading arm	5.49 ± 2.43	3.95 ± 2.33	**.01***	0.65
		Trailing arm	0.27 ± 0.17	0.21 ± 0.11	.40	0.39

*$p < .05$

Flexor/ extensor ratio of upper extremity

Table 5 presents the flexors/ extensor ratios for the normalized EMG for two strokes in both phases. During the preparation phase, the ratio of the wrist in the trailing arm was significantly higher for the groundstroke (0.74 ± 0.44) than drive volley (0.59 ± 0.35); both ratios were <1, which shows the drive volley had more extension in the wrist. During the early acceleration phase, the ratio of the wrist in the trailing arm was significantly higher for the groundstroke (1.25 ± 0.98) than drive volley (1.01 ± 0.87); ratios were >1, which shows that drive volley had less flexion in the wrist. Moreover, during the late follow-through phase, the ratio of the leading elbow was significantly higher for the drive volley (5.49 ± 2.43) compared with the groundstroke (3.95 ± 2.33); ratios were >1, which means that drive volley had more flexion in the elbow of the leading arm.

Discussion

The purpose of this study is to uncover differences in the swing kinematics of racket tip and wrist/ elbow muscle activation strategies between the drive volley and groundstroke in tennis two-hand backhand of the female players. Results found that the drive volley was shorter in terms of preparation, but longer in follow-through. In terms of muscle activation, the preparation and early acceleration phases had slight differences. The most variation in muscle activation strategy between both strokes occurred in the late follow-through phase. Besides, the limitation of this study is the exclusion of different grips on the trailing arm. Although previous studies have pointed out that different grips on the trailing arm would affect the elbow and wrist (Busuttil et al., 2020), our study compared the individual drive volley and groundstroke of each subject. This study therefore emphasizes muscle activation level between the drive and groundstroke.

Moreover, in the stroke performance of racket tip kinematics, the drive volley typically exhibited higher vertical velocities, while the groundstroke had higher horizontal velocities. This finding thereby supports coaching experience proposing that the drive volley requires comparatively more vertical (bottom-up) power (Rive and Williams, 2011). The groundstroke also produced higher resultant velocities than the drive volley. In addition to the swing duration in each phase, the drive volley had a shorter preparation phase but a longer follow-through phase. And velocity of the drive volley was less from the late acceleration phase to the late follow-through phase than the groundstroke. Reasons for this outcome might be the higher velocity of the oncoming ball, the short reaction time in drive volley due to not having bounce, and the shorter distance between the players' hitting position and the target area. As for the greater momentum from the oncoming ball, the drive volley stroke exhibited more difficultly in accelerating forward movement than the groundstroke.

To enhance our understanding and clarify the muscle activation strategies in the skill difference between both strokes, specific data on the five phases are presented.

Preparation phase. The drive volley demonstrated higher ECR trailing arm activation (Table 4) and more remarkable wrist extension behavior with a smaller flexor/ extensor ratio at the wrist trailing arm (DV:0.59 ± 0.35, GS:0.74 ± 0.44) (Table 5). Also, there was significantly higher TB trailing arm activation (Table 4) but the flexor/ extensor ratio of the elbow was close to 1 (1.07 ± 0.54) (Table 5). We therefore speculated that more TB activation was used to increase stability of the elbow joint during the backswing. Higher activity in these muscles in the drive volley thus enabled a shortened backswing in the preparation phase. This is supported by swing duration data of the shorter preparation phase (Table 2). Also, the ECR trailing arm has agonist muscles that quickly turn the racket into an open racket-face (racket-face side to backhand side) during the backswing.

This phenomenon might be explained by the concept of wrist muscle interaction torque in throwing studies, which found that this muscle torque increased with throwing speed, but counteracted the interaction torque to precisely control its release timing during a limited time period (Hirashima et al., 2003; Debicki et al., 2011). As the TB trailing arm would help the elbow get stable/ fixed to reach the end of the backswing quickly, this is one reason to increase the distance over which velocity can be developed during the forward swing (Aleksovski, 2013). Results of racket velocity performance also reflect a slower drive volley.

Early acceleration phase. Activation of the FCR leading arm in the drive volley was higher than groundstroke (Table 3), and the flexor/ extensor ratio of the wrist was not close to 1 (DV: 2.10 ± 0.94) (Table 5), which means it may act to modulate the wrist in reacting to impact. Previous studies have suggested that the forward-moving extension of the wrist in the leading arm during the acceleration phase, as well as a concentric coactivation of wrist muscles during ball impact, provide advantageous in avoiding the risk of lateral epicondylitis (Blackwell and Cole, 1994; Knudson and Blackwell, 1997). Kelley et al. (1994) also found that recruitment of the FCR muscle for players who recently recovered from lateral epicondylitis (tennis elbow) was more vigorous than for healthy players in the early acceleration phase; the muscle activation strategy of the drive volley was used to recruit the FRC leading arm earlier to collaborate wrist joint to protect the elbow from the impending impact. Hence, drive volley would recruit the FCR leading arm earlier to maintain wrist stability.

Study results also show that in the trailing arm, the less flexor/ extensor ratio of the wrist in the drive volley was close to 1 (DV: 1.01 ± 0.87, GS:1.29 ± 0.98) (Table 5), which means that muscle activity of drive volley was characterized by a more co-contraction pattern within this phase. More FCR leading arm activity and co-contraction in the wrist trailing arm during the early acceleration phase were thus recorded in the drive volley, as it employed a more significant impact momentum from the racket-ball contact to maintain wrist stability.

Late acceleration and early follow-through phases. The times of bordered impact showed no significant differences in the muscle activation strategies between the two strokes in either arm, surprisingly. This may explain why both strokes produced considerable impact force on the hand. The late acceleration and early follow-through phases exhibited the highest activation levels for the upper arm muscles, as shown by Morris et al. (1989) and Wei et al. (2006). A relatively firm grip was also used in impact to avoid the risk of upper extremity injury from the vibration generated by external force of impact (Chow et al., 1999; Wei et al., 2006). Therefore, the drive volley and groundstroke require a relatively firm grip in timings of bordered impact. Thus our assumption that the muscle activation of two strokes will be different especially close to impact was not supported.

It is not surprising that FCR and ECR were activated to stabilize the wrist joint in this study, however. After all, stability of the upper extremity joints can prevent injury to muscle tissue from the significant vibrations that occur with impact. A similar muscle activation pattern was found between two stroke techniques through the late acceleration and early follow-through phases. This implies that our assumption regarding the muscle activation of two strokes will be different and especially close to impact is overthrown because it is necessary to maintain a high muscle activation level of the upper extremity immediately before and after impact. This protects the muscle tissue by counteracting the external force during impact (Rogowski et al., 2011).

Late follow-through phase. TB leading arm activity in the drive volley was significantly less than in the groundstroke (Table 3). The flexor/ extensor ratio of the elbow joint (Table 5) also showed less flexion in the drive volley. Stępień (2012) reported that the TB activation leading arm of the backhand was related to the different elbow joint angular positions, as TB muscle is primarily responsible for elbow joint extension. Our study found that the drive volley had less TB activation and a flexor/ extensor ratio >1 in the late follow-through phase, demonstrating that less elbow extension movement was used in the drive volley with the leading arm throughout the follow-through. Furthermore, the ECR muscle in the drive volley was significantly more activated than the groundstroke in the trailing arm (Table 4), where it also maintained the wrist flexion angle with the racket face in late follow-through. A forehand EMG study reported that ECR would quickly deactivate after the impact (Rogowski et al., 2009). We found that the drive volley had a higher ECR trailing arm, which activates significantly compared to the groundstroke in the late follow-through phase. This means that the ECR trailing arm was activated longer in the follow-through for the drive volley.

We deduced that this phenomenon of higher ECR trailing arm activation at the end of the forward movement indicates that the drive volley needs more forward compression movement to increase shot efficiency. The longer impulse for the racket contact with the ball and the actively ECR trailing arm would thus help to maintain racket face stability. The swing kinematic results of the racket indicate a longer swing duration and slower average velocity for the drive volley during the late follow-through phase. The biggest difference in the implementation of the two strokes occurred in the late follow-through phase. Better stroke efficiency with the longer impulse for ball contact, and less elbow extension of the leading arm and the higher ECR trailing arm, were found to play essential roles.

Conclusion

This study is the first to provide muscle activation data on the upper extremity in the drive volley via exploration of EMG activation patterns during each phase of the drive volley and two-handed groundstroke. Compared with the groundstroke, the characterized drive volley perspective is found to have a higher vertical racket velocity, whereas the groundstroke has a higher horizontal velocity. In addition, the drive volley has a shorter preparation but longer follow-through. In muscle activation strategies, the ECR and TB in the trailing arm thus play an important role in quickly completing the backswing during the preparation phase. In our study, most differences of technical between both strokes were during late follow-through, where the drive volley was consistently rigid/ locked but the groundstroke used a released strategy on the upper extremity. In terms of injury prevention, results show that the drive volley needs more wrist stabilization in the acceleration phase, which requires earlier recruitment of the FCR leading arm compared with the groundstroke. Also, in the timings bordered at impact, stroke techniques recruited showed high-level activation against violent impact. We find that the drive volley early stiff activation strategy may have more risk, due to the transferred force of the elbow and wrist being elongated while under tension. Therefore, coaches should consider the characteristics of and differences between the two techniques in training programs; particular attention should be given to wrist stability in the acceleration phase and follow-through to avoid the risk of injuries when performing the drive volley. To reduce the risk of injury, overspeed training through the practice of the drive volley can improve the velocity and thus shorten the time for the backswing phase, and also increase the level of wrist stabilization in the stroke both before and after the impact.

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Key points

- This study is the first to provide muscle activation data on the upper extremity in the drive volley via exploration of EMG activation patterns during each phase of the drive volley.
- Compared with the groundstroke, the swing characterized drive volley perspective is found to have a higher vertical racket velocity, whereas the groundstroke has a higher horizontal velocity. In addition, the drive volley has a shorter preparation but longer follow-through.
- In muscle activation strategies for the drive volley, the ECR and TB trailing arm play an important role in quickly completing the backswing during the preparation phase. The earlier recruitment of the FCR leading arm is the requirement of wrist stabilization during the early acceleration phase. The longer ECR trailing arm maintains racket face stability during the late follow-through phase.
- In the timings bordered at impact, the assumption regarding the muscle activation of two strokes will be different especially close to impact was not supported, due to high-level activation against violent impact.

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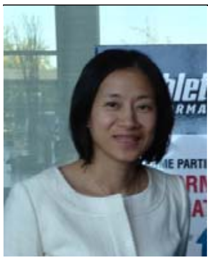

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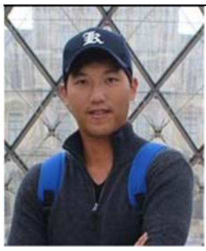

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