UPPER LIMB KINEMATICS DURING THE TOPSPIN DOUBLE-HANDED BACKHAND STROKE IN TENNIS

Nicholas A. Busuttil[1], Machar Reid[2], Molly Connolly[2,3], Ben J. Dascombe[4] & Kane J. Middleton[1]

Sport and Exercise Science, School of Allied Health, Human Services, and Sport, La Trobe University, Melbourne, Australia[1]
Game Insight Group, Tennis Australia, Melbourne, Australia[2]
Institute for Health and Sport, Victoria University, Melbourne, Australia[3]
Applied Sport Science and Exercise Testing Laboratory, School of Life and Environmental Sciences, University of Newcastle, Ourimbah, Australia[4]

The purpose of this study was to compare non-dominant wrist kinematics during tennis double-handed backhand strokes in players using either an eastern or continental grip position. Trajectory data for two grips (eastern & continental) and depths (deep & short) were captured for sixteen sub-elite right-handed tennis players using a 12-camera Vicon motion capture system (250 Hz). The eastern grip demonstrated significantly faster horizontal racket head velocities compared to the continental grip. However, no differences were observed in accuracy or spin rate between grips ($p > 0.05$). In the non-dominant upper limb for the continental condition, elbow flexion was smaller while wrist extension was larger throughout the swing. Collectively, these data suggest that the continental grip may place the wrist in a position that is more vulnerable to overuse injury.

KEYWORDS: ulna, wrist, kinematics, grip, tennis.

INTRODUCTION: Acute wrist pain is among the most common issues reported by elite and recreational tennis players, and it is a likely result of the wrist being the first major upper limb joint to absorb ball impact forces (Stuelcken, Mellifont, Gorman, & Sayers, 2017; Elliott, 2006). During the 2011-2016 Australian Opens, the dominant and non-dominant wrists were the 3rd and 5th most commonly injured regions for all players, respectively (Gescheit et al., 2017). Commonly hypothesised mechanisms of ulnar-side wrist injuries in racket sports are repetitive and sudden pronation of the forearm from a supinated position and forced eccentric overloading of the wrist flexors (Knudson & Bahamonde, 2001). The most implemented grip on the professional circuit is the eastern grip, followed by the continental position, which are also the most common grips for the non-dominant and dominant hand in double-handed backhands (Eng & Hagler, 2014). When the racket is vertically aligned to the baseline, the continental grip positions the palm of the hand superiorly to the racket handle, and more pronated compared with the eastern grip. Studies have assessed grip position on upper limb kinematics in the single-handed backhand drives and forehands (Elliott & Christmass 1994; Elliott, Takahashi, & 1997), however is limited for double-handed backhands.
The aim of this study was to compare the upper limb kinematics of tennis players using two non-dominant hand grip variations (eastern and continental) during a double-handed backhand while aiming crosscourt to either a short or deep target. It was hypothesised that the use of the continental grip with the non-dominant hand would result in greater ulnar deviation, and less wrist extension throughout the swing compared with the eastern grip. It was also hypothesised that greater ulnar deviation would occur in the non-dominant wrist during a double-handed backhand stroke that was short in the court rather than deep in the court.

METHODS: Sixteen right-handed sub-elite adolescent tennis players who had competed at Australian state and/or national level ranking tournaments agreed to participate in the study. All testing was completed on an indoor court at the National Tennis Centre, Melbourne, Australia. Participants used their own racket during the testing to ensure that swinging mechanics were unaffected whilst performing each backhand stroke. The participants were required to perform successive backhand attempts into two separate marked crosscourt target

zones (target size: 2.5 m x 2.5 m) at the baseline (Deep [D]) and service line (Short [S]). First, participants were instructed to hit a series of topspin double-handed backhand strokes aiming crosscourt for a selected target zone using their preferred non-dominant grip position (eastern forehand [E]). Once five successful backhands were completed separately at each depth (ED & ES), the participants then repeated the protocol using their non-preferred grip (continental deep [CD] and short [CS]). The participants received a controlled pre-impact ball velocity of 20 m/s via a Spinfire Pro 2 ball machine (Fry Developments Pty Ltd, Melbourne, Australia) which was directed along the left singles line. Marker trajectories were captured using a 12-camera Vicon Vantage motion capture system (Vicon Motion Systems Ltd., Oxford, UK; 250 Hz). Fifty-four reflective markers (12 mm in diameter) were attached to the shoulders and upper limbs of each participant, using rigid clusters and single markers (Wells, Donnelly, Elliott, Middleton, & Alderson, 2018; Whiteside, Elliott, Lay, & Reid, 2015). An additional six light rubber markers (12 mm in diameter) were placed on each participant's racket. Individual marker coordinates were reconstructed with Nexus software (Vicon Motion Systems Ltd., Oxford, UK, V 2.7.0) where marker trajectories were filled using spline, pattern or rigid 'gap filling' functions. Marker trajectories were then filtered using a Woltring filter with a mean square error of 0.1. A nine-segment linked upper limb kinematic model was applied to the data with the racket modelled as an additional segment (Wells et al., 2018, Whiteside et al., 2015).
Performance outcomes were assessed whilst ball kinematics were measured using the Hawk-Eye ball tracking system (accuracy [% acc], post-impact speed [m/s] and spin rate [rev/s]). Joint angles (°) for the shoulder (flexion/extension, internal/external rotation), elbow (flexion/extension, pronation supination) and wrist (flexion/extension, ulnar/radial deviation) were calculated for both upper limbs. Racket angles ([°] horizontal angle, vertical angle, and racket tilt; at peak backswing and impact) and racket head linear velocities (m/s) were also computed. Horizontal racket angle was defined as global racket rotation in the transverse plane, vertical racket angle was defined as global racket angle in the coronal plane, and racket tilt was defined as global racket angle in the sagittal plane. A neutral (0°) angle was recorded when the racket face was vertically aligned and parallel to the net, where negative and positive angles represent a closed and open racket face respectively. The time points of interest for data analysis were at the instance of peak backswing and impact. The first three successful backhands from each condition (total of 12 trials) were used for analysis using Jamovi (v 1.1.8.0, Jamovi project). A two-way repeated-measures analysis of variance was used to assess the main effects of, and interaction between, grip type and stroke depth. An alpha level of .05 was used for all statistical analyses.

RESULTS: There were no significant interactions observed for ball or racket variable at peak backswing or impact ($p > 0.05$; Table 1). Significant main effects of grip type ($p < 0.001$) and shot depth ($p = 0.021$) were observed for horizontal racket head speed, whereby the eastern grip ([mean ± SD]; 15.6 ± 2.1 m/s) and deep shot depth (15.1 ± 2.2 m/s) resulted in greater horizontal racket head speed compared with the continental grip (13.5 ± 2.2 m/s) and short shot depth (13.8 ± 2.1 m/s), respectively. A main effect of shot depth was observed for percentage accuracy ($p = 0.008$), with the short conditions (28.8 ± 12.2%) demonstrating significantly greater accuracy than the deep conditions (21.1 ± 8.7%). An effect of grip type for post-impact ball speed ($p = 0.013$) and shot depth ($p < 0.001$) was detected, whereby the eastern grip (26.9 ± 2.0 m/s) and deep shot depth (28.0 ± 2.4 m/s) resulted in greater speed compared with the continental grip (25.4 ± 2.3 m/s) and short shot depth (23.4 ± 1.9 m/s).
No significant interactions were observed at peak backswing nor impact for any upper limb joint variable, however at peak backswing a main effect of grip type was observed for non-dominant elbow extension, ($p = 0.008$). The elbow demonstrated greater extension when using a continental grip (51.8 ± 25.6°) when compared with the eastern grip (68.8 ± 24.0°). Shot depth was observed to effect horizontal racket angle ($p = 0.05$), with the deep shot resulting in greater forward racket head displacement in the horizontal plane (122.0 ± 23.4°) compared with the short shot (111.5 ± 18.3°). All remaining racket and upper limb variables at peak backswing resulted in no significant main effects for grip type nor shot depth.

At impact, the non-dominant wrist (p = 0.047) and elbow (p = 0.005) demonstrated greater extension when using the continental grip (wrist: -43.0 ± 16.7°, elbow: 46.8 ± 20.1°) compared with the eastern grip (wrist: -34.7 ± 16.0°, elbow: 60.9 ± 20.3°). For horizontal racket angle, a significant main effect of shot depth was observed, whereby the racket rotated 3.7° further forward during the short shots compared with the deep shots (p < 0.001). Significant main effects for grip type (p = 0.025) and shot depth (p < 0.001) were found for racket tilt, with the short shot (-5.1 ± 5.0°) and eastern grip (-4.2 ± 4.3°) impacting the ball with a more closed racket face compared with the deep shot (-0.7 ± 4.1°) and continental grip (-1.6 ± 4.8°), respectively. There were no other significant main effects identified for grip type or shot depth.

Table 1. Ball and racket kinematics (mean ± SD) during short and deep strokes across grips.

	Deep		**Short**	
Ball and Racket Kinematics	**Eastern**	**Continental**	**Eastern**	**Continental**
Racket Speed at Impact (m/s)				
Horizontal velocity of racket***^**	16.4 ± 2.1	13.8 ± 2.2	14.5 ± 2.1	13.1 ± 2.1
Vertical velocity of racket	8.3 ± 3.0	6.9 ± 3.4	9.4 ± 2.9	7.9 ± 3.2
Ball Kinematics				
% Accuracy**^**	21.2 ± 9.6	21.0 ± 7.7	30.4 ± 10.2	27.1 ± 14.2
Post-impact speed (m/s)***^**	29.1 ± 2.4	26.8 ± 2.3	24.6 ± 1.5	23.9 ± 2.3
Spin rate (rev/s)	25.0 ± 6.0	23.0 ± 4.9	23.8 ± 4.5	23.3 ± 5.2

* indicates a main effect of grip type; ^ indicates a main effect of shot depth; p < .05.

DISCUSSION: The present study is the first to explore upper limb kinematic differences between an eastern and continental grip of the double-handed backhand in sub-elite adolescent tennis players. Our initial hypotheses were not supported as the use of the continental grip did not result in reduced wrist extension nor greater ulnar deviation compared with the eastern grip in the non-dominant limb, nor was greater ulnar deviation evident in the short crosscourt shots compared with the deep shots. At peak backswing, the non-dominant elbow was more extended in the continental grip compared with the eastern grip which possibly created a larger horizontal racket angle at peak backswing, which was also observed in the deep shot depth compared with the short shot depth. Larger horizontal racket angles, corresponding with extended elbow joints as observed in the deep shot may imply that faster racket head and ball speeds are able to be generated due to the racket travelling a greater distance to impact. The deep shot ball speed was approximately 2.3 m/s greater in the eastern grip compared with the continental grip. Reducing preparation time for opponents is critical in tennis and can be achieved from greater horizontal racket velocity. This may then increase difficulty for opponents to return the ball from their reduced preparation time. Additionally, using the continental grip at the non-dominant limb possibly disrupted the coordination of upper limb joint rotations during the forward swing. The athletes were experienced in the eastern grip position and possibly explains the reduced speed observed for the continental conditions.

The players possibly adopted a more closed racket face to impart increased ball spin, however this was not achieved in the present study. Greater spin rates, coupled with increased post-impact ball speed, would likely increase the difficulty for opponents to return an effective stroke. The continental grip in the non-dominant limb was executed with a more extended elbow and wrist joint at impact but had similar ulnar deviation. The more extended elbow possibly reduced the subsequent racket head speed as previously extended elbow positions have resulted in decreased forward horizontal racket velocity during the serve (Elliott, Marshall, & Noffal, 1995). Previous cadaveric research has shown that relative load bearing (between the radius and ulna) at the distal radio-ulna joint is positively associated with ulna deviation. In neutral wrist flexion/extension, 15° and 25° of ulnar deviation placed a mean relative load through the distal ulna of 20% and 24% respectively, presenting an increasing load trend (af Ekenstam, Palmer, & Glisson, 1984). The present study exhibited ulnar deviation above 30° at impact for the non-dominant wrist. This may suggest that the relative load at impact through the distal ulna may be considerably greater during a dynamic movement such as the double-handed backhand, which may serve as a mechanism for the development of ulnar-side wrist pain. Recent radiological examination suggests that non-dominant ulnar-side wrist pain is primarily a result of repetitive *extensor carpi ulnaris* muscle use (Reid et al., 2020). Maximal wrist extension has shown to reduce isometric grip flexor force compared with a neutrally oriented wrist as the muscles are not at an optimal physiological length to develop force (Susta, & O'Connell, 2009), likely to result in racket and grip instability. The continental grip may be perceived as a 'weak' grip position for tennis groundstrokes as it is neutrally orientated in the sagittal plane (flexion/extension). The neutral wrist position has been documented where maximal grip force is likely achieved, however force capacity reduces significantly when in ulnar deviation (Fong & Ng, 2001). The *extensor carpi ulnaris* muscle acts as a dynamic wrist joint stabiliser when in neutral orientation (Iida et al., 2012) and possibly accounts for the greater displacement in extension for the continental conditions. Therefore, the continental grip may not be an optimal load bearing position for the non-dominant limb, possibly increasing joint forces experienced at the wrist in tennis double-handed backhands.

CONCLUSION: This study demonstrated that a change in non-dominant hand grip position during tennis double-handed backhands resulted in limited kinematic differences across the non-dominant limb. The hypotheses were not directly supported as ulnar deviation remained similar between both grips and shot depths, and wrist extension was greater in the continental condition. Shot accuracy and ball spin were comparable between conditions, though the eastern grip produced greater ball speeds. Using the eastern grip may provide greater structural support to the non-dominant elbow and wrist joint, where using the continental grip may place the non-dominant wrist joint in a position of increased stress and joint motion, becoming more vulnerable to overuse injury. This information may provide coaches a better understanding of upper limb joint positions at swing onset and impact in double-handed backhands which would be beneficial for coaches developing young tennis athletes.

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