TENNIS ONE-HANDED BACKHAND STROKE AT DIFFERENT IMPACT HEIGHTS

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The purpose of this study was to compare the kinematic differences of the racket during a one-handed backhand stroke at different impact heights. Five male collegiate tennis players were instructed to stroke the incoming balls from different heights to a crosscourt target area. The impact heights were classified as High, Middle, and Low. Significant differences were observed at 3 heights for racket angles ($p < 0.05$). The decrease of the angular velocity of upper trunk right-lateral rotation at High might be the main element that resulted in a decrease in the resultant velocity of the racket at impact. The greater moment of inertia of the dominant arm and racket about shoulder horizontal abduction-adduction axis at High made arm difficult to be accelerated. It might influence the velocity and control of the one-handed backhand stroke at high impact point.

KEYWORDS: moment of inertia, upper trunk, racket angles and velocities.

INTRODUCTION: In a tennis match, serving and returning balls to the opponent's backhand side is a basic tactic due the backhand usually being considered as the weak side (Bailey and McGarrity, 2012), and the backhand has researched less than serve and forehand (Genevois et al., 2015). Studies have explored racket velocities of the one- and two-handed backhand (Reid and Elliott, 2002), and post-impact ball velocities (Fanchiang et al., 2013). However, few studies have considered the conditions of incoming balls, such as heights, velocity, spin and how this influences the racket orientation and swing motion against the different incoming balls. The population of one-handed players is much considerably less when compared to two-handed players, and the one-handed backhand being considered more difficult to be proficient at (Groppel, 1984). From practical observation, it is logical to assume that it is harder to hit the ball with a one-handed backhand stroke at higher impact zones. The hypothesized advantage of the two-handed backhand is that the second hand provides more strength to the stroke. The dominant arm of one-handed backhand may also undertake more adjustments when forced to return balls from differing heights. Therefore, the purposes of this study were to compare the differences of racket kinematics at impact during one-handed backhand strokes at different impact heights, and to investigate some elements of the upper trunk and dominant arm that may be responsible for making the one-handed backhand harder to be proficient at.

METHODS: Five male collegiate one-handed backhand players (age: 25.6±10.0y, height: 1.72±0.03m; body mass: 71.0±2.8kg) who were right-handed and used an eastern grip participated in this experiment. This study was approved by the University of Tsukuba Human Ethics Committee. The contents of the experiment and this study were explained to all participants and they signed a written informed consent form prior to the experiment. The participates were instructed to strike the incoming balls from different heights into a 2x2m target area with a one-handed backhand stroke in a laboratory environment (Figure 1a). The ball was fed by a server with racket to give the participants time for prediction and preparation. Four reflective markers were attached to the racket head (RHED), bottom (RBTM), and each side of the racket face (RFML, RFMM). Forty-seven reflective markers were attached to the body based on previous study (Suzuki et al., 2014). A three-dimensional motion capture system (VICON-MX, 14 cameras, 500Hz) was used to obtain the coordinates of all markers. The coordinate values were smoothed using a Butterworth low-pass filter with optimal cut-off frequencies from that range between 15 to 30 Hz (Winter, 2009) for all trials.
Temporal analysis of the movement was taken from the start of racket downswing to 1 frame (0.002s) prior to the ball impact (Figure 1b) and motion time was normalized to 100%. The

impact was defined as the instant of the maximum deceleration of racket head. Impact heights were defined as the middle point of RFML and RFMM at impact. The impact heights above the shoulder joint were defined as high impact heights (High); between the hip and shoulder joints being defined as middle impact heights (Mid); below the hip joint being defined as low impact heights (Low). The impact heights were proportioned to each participant's height. The global coordinate system was defined with, the Y-axis being along the side-line, the X-axis being along the baseline, and the Z-axis being the cross product of X-axis and Y-axis (Figure 1a). The local coordinate system of the racket was defined as z_{racket} axis was aligned to the racket's longitudinal axis pointing to the handle, and x_{racket} axis being perpendicular to the racket longitudinal axis and parallel to the racket face, the y_{racket} axis being perpendicular to x_{racket} and z_{racket} axes (Figure 1c). The velocity of the middle point of RFML and RFMM represented the velocity of the racket in this study. For the upper trunk, the vector from RIBC to XIPC was defined as z_{utrk}, y_{utrk} being defined as the cross product of the z_{utrk} and the support vector s_{utrk} from SHDL to SHDR, and x_{utrk} defined as the cross product of y_{utrk} and z_{utrk}. The longitude axis of upper trunk represented the z_{shHAA} in this study (Figure 1e).
The racket kinematics of horizontal velocity, vertical velocity, face angle and spin angle were calculated at ball impact. The correlation between upper trunk flexion(-)/extension(+) angle relative to the global coordinate system at impact and impact heights were examined, and the angular velocity of the upper trunk left(-)/right(+)-lateral rotation about longitude axis (z_{utrk}) was calculated. In order to evaluate the degree of difficulty of the angular acceleration of the dominant arm, the horizontal adduction-abduction axis of the shoulder joint (Z_{shHAA}) was selected and the moment of inertial of dominant arm and racket about this joint axis (MOI) was calculated by using parallel axis theorem (Robertson et al., 2014). Figure 1d shows the definitions of the racket face and spin angles referred to the definitions by Reid and Elliott (2002). The racket kinematics at impact were examined using an ANOVA and the correlation between the upper trunk flexion(-)/extension(+) angle and impact heights was also calculated on SPSS Statistics 25.0 for Windows (IBM, Tokyo, Japan). The level of statistical significance was set at $p<0.05$.

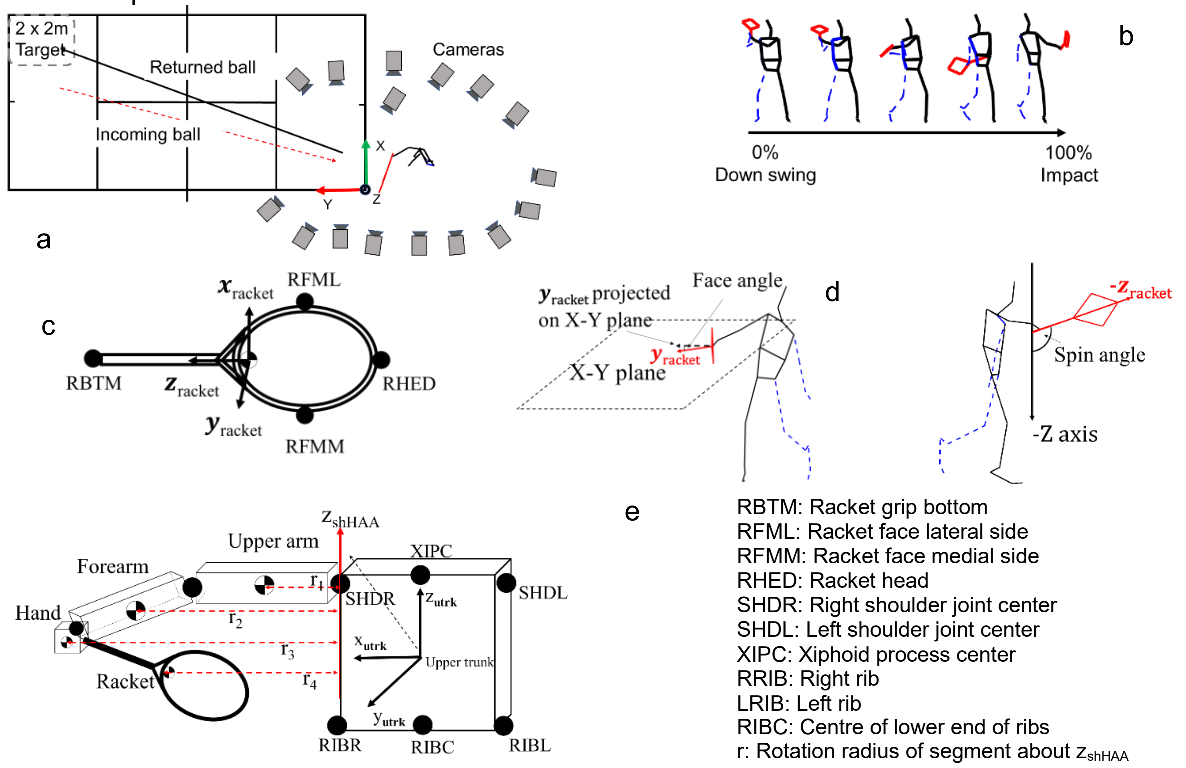

Figure 1 a: experimental setup, b: range of temporal analysis of the movement, c: marker position and the local coordinate system of racket, d: definition of racket angles, e: local coordinate system of upper trunk, the z_{shHAA} of shoulder joint.

RESULTS: Table 1 shows the mean and standard deviations of the impact heights, its % ratio of body height, the racket angles, and racket velocities. The racket face angle at High was found to be significantly smaller than the Mid and Low ($p < 0.05$) and the Mid also being smaller than the Low ($p < 0.05$). The racket spin angle at High was greater than the Mid and Low ($p < 0.05$) and the Mid was greater than the Low ($p < 0.05$). For the horizontal velocity of the racket, no significant difference was observed between the 3 impact heights ($p > 0.05$). For the vertical velocity of the racket, no significant difference was observed between Mid and Low ($p > 0.05$). Whereas the vertical velocity at High was smaller than that at Mid and Low ($p < 0.05$). The resultant velocity of the racket at High was significantly smaller than that at Mid and Low ($p < 0.05$). Figure 2a shows the correlation between flexion(-)/extension(+) angle of the upper trunk at impact and impact heights. As the impact heights became higher, the upper trunk extended more posteriorly (R=0.76, $p < 0.05$). The MOI increased slightly from 0 to 70% of normalized time at three heights (Figure 2b). From 70 to 100% of normalized time, the MOI continuously increased at High, whereas the MOI decreased from 70 to 90% of normalized time and then increased until 100% of normalized time at Low and Mid. The MOI at Low decreased more than that at Mid. From 80% of normalized time to impact, the MOI was greater as the impact height increased. Figure 2c shows the angular velocity of upper trunk about z_{utrk} at 3 heights. The angular velocity changed slightly from 0 to 60% of normalized time. The peak value and the value at impact of angular velocities of upper trunk right-lateral rotation at High were smaller than that at Low and Mid.

Table 1 mean and standard deviations of Impact heights and the racket kinematics at impact

			Racket angles		Racket velocities		
Impact height	Height [m]	Ratio of body height [%]	Face angle [deg]	Spin angle [deg]	Horizontal [m/s]	Vertical [m/s]	Resultant [m/s]
High	1.44±0.11	85.0±6.2	-4.0±1.2*†	106.5±9.2*†	22.2±3.8	8.9±2.9*†	23.9±3.3*†
Mid	1.16±0.03	68.6±1.5	0.6±1.9‡	92.7±4.9‡	24.4±3.1	10.2±3.1	26.7±1.9
Low	0.83±0.05	49.1±1.9	3.4±3.6	78.7±6.8	24.1±2.5	11.0±3.1	26.7±2.1

Note: *: High vs. Mid, †: High vs. Low, ‡: Mid vs. Low. p<0.05.

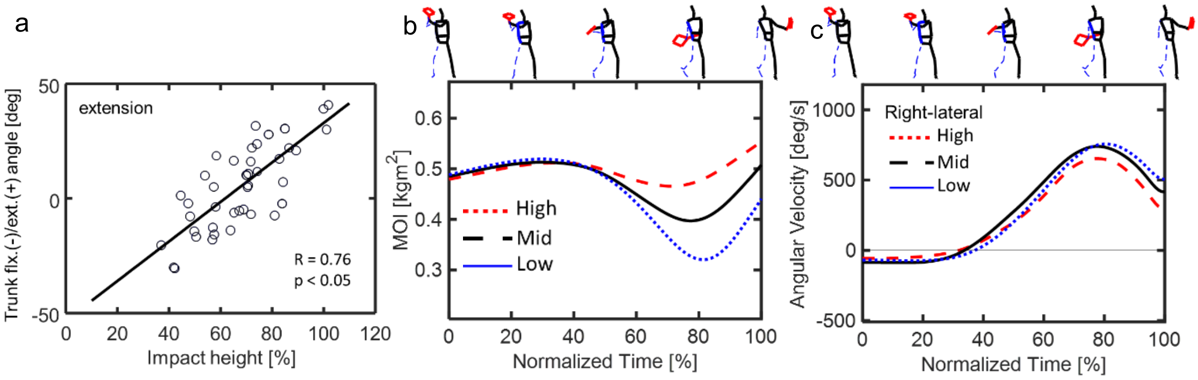

Figure 2 a: correlation between impact height and upper trunk lean angle, b: MOI, c: angular velocity of upper trunk left(-)/right(+)-lateral rotation about z_{utk}.

DISCUSSION: The racket face angle at Low (3.4 ± 3.6 deg) was similar to the previous study (Reid & Elliott, 2002). At Low, the impact height (0.83 ± 0.05 m) was lower than the height of the net (0.914 m). It was considered that an open face was helpful in allowing the ball to cross the net and landing in the deep area close to the baseline. As the impact height increased, the impact height was higher than that of the net. It is thought that an oblique racket face (-4.0 ± 1.2 deg) could give ball more spin rate and keep the ball landing inside of the baseline with Magnus effect. The racket spin angle at High (106.5 ± 9.2 deg) increased significantly, which indicated that the player increased the racket spin angle to reach a higher impact point. The angular changes of the racket indicated that it required players have more precise control to adjust the racket angle during forwarding swing by one hand against the balls from different heights.

Bahamonde (2003) reported that optimal trunk rotation was one of the most important elements of forehand and backhand strokes. The rotation of the trunk is most important for generating stroke power, which is supported by other researchers (Groppel, 1994). In this study, the smaller angular velocity of the upper trunk at High may be the reason that was seem a decrease in the resultant velocity of the racket head. Reid & Elliot (2002) reported that the trunk backward lean angle of one-handed backhand was greater than that of two-handed backhand. Wang et al. (2010) investigated the momentum transformation in the two-handed backhand, in which it was reported that a larger backward linear momentum component decreases the body stability and wastes energy. In this study, the upper trunk at High extended more posteriorly at impact, which made the body apart away from the stroke direction, which was considered that the trunk might contribute less linear momentum forward to the stroke. The lager MOI at High was considered that it was more difficult to accelerate the dominant arm in the direction of the horizontal abduction and the muscles around the shoulder may need to exert more forces when the 'kinetic chain' is not applied sufficiently. This might cause the player to decrease the angular velocity of upper trunk right-lateral rotation to accelerate the dominant arm. Reid & Elliot (2002) reported that the ball was impact further in front of the body compared to two-handed backhand stroke. The difficulty of accelerating the dominant arm in the direction of the horizontal abduction and maintaining the impact position further in front of the body may be the essential factors contributing the one-handed backhand stroke being more difficult at High. Interestedly to note that it took more strokes to obtain the successful trials for the High and most of unsuccessful stokes were landing closer to the net, which might imply that stroke accuracy, control, speed decreased easily at High. This may help explain why one-handed backhand players use more slice when returning the high incoming ball.

CONCLUSION: The differences of racket angles and velocities, the dominant arm and upper trunk during the one-handed backhand stroke have been compared. The resultant velocity of the racket head at High was smaller than that at Mid and Low at impact. It is possible that the players decrease the speed to maintain the accuracy of the stroke when returning the high incoming balls. It is thought that the decrease of the angular velocity of the trunk is linked to the decrease of the resultant velocity of the racket head. The larger MOI at High during forward swing is linked to make the dominant arm more difficult to be accelerated. This study provided some evidence that it is more difficult to perform a one-handed backhand stokes when returning balls at a high impact height. This finding might help players and coaches to formulate the strategies when facing the incoming balls from different heights and select appropriate training methods to improve one-handed backhand stroke techniques.

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