JOINT FORCES AND TORQUES OF THE UPPER EXTREMITY DURING STANDING SMASH AND JUMPING SMASH IN SOFT-TENNIS

Hirofumi Ida, Seiji Kusubori, Tomoko Nakamura, Kazuhiro Suda, Motonobu Ishii
Graduate School of Decision Science and Technology,
Tokyo Institute of Technology, Tokyo, Japan

Both standing smash (SS) and jumping smash (JS) use the overhand swing, but are under different conditions from the viewpoint of external force. These two trials were filmed by two synchronized high-speed cameras (250Hz) and 3-D data were obtained using the direct linear transformation procedure. As kinematical data, linear resultant velocity of the racket head and absolute joint angles of upper extremity did not show any significant difference; as for kinetical analysis, joint forces and torques of upper extremity were calculated anatomically. There were no apparent differences in general temporal variations. However, about the shoulder adduction and horizontal adduction torques near initiation of forward swing (IFS), torque peaks of the JS appeared later than that of the SS. Additionally, elbow anterior force of the JS was larger than that of the SS.

KEY WORDS: soft-tennis, standing smash, jumping smash, joint force, joint torque

INTRODUCTION: Soft-tennis is played using a light racket with rubber balls. Both singles and doubles are played, however doubles is the more popular of the two. In the doubles game, a one-up-one-back formation is usually adopted. In this formation, the volleyer should make powerful volleys and smashes to gain points. Previous studies (Elliott et al., 1986) revealed many important aspects of tennis motion. And today, kinetic studies of sports motions (Feltner and Dapena, 1986) are on the increase and will throw new light on effective motion of sports. The purpose of this study was to clarify the motions of standing smash (SS) and jumping smash (JS) from the kinematic and kinetic viewpoint. Figure 1 shows a typical motion of each technique. In soft-tennis standard SS, players (right-handed) will initially place their right foot, followed by the swing of the racket and then transfer the bodies toward their left foot while placed on the floor. In JS, players jump by pushing off the ground with the right leg and hit the ball in the air immediately before landing with his left leg. Detailed reports of smash motion are few in the game of tennis; however these two techniques have interesting dynamic aspects. During the SS swing, gravity and ground reaction force mainly affect the player's body; on the other hand, in the JS swing only gravity acts during most of the swing (air resistance force is not considered here). Do kinematics and/or kinetics of the racket swing show any difference under these different dynamic environments?

METHODS: The subjects were right-handed skilled soft-tennis volleyers (8 male, age = 23.5 ± 5.6 years, height = 1.73 ± 0.04 m, weight = 67.1 ± 4.5 kg) including the varsity runner-up team at the All-Japan College Soft-Tennis Championship (2000). The control area was constructed around the center of the court and subjects were required to smash toward the target area that was set in the "cross" direction of the opponent's court. Motions of SS and JS (Fig. 1) were filmed using the two electrically synchronized high-speed cameras (NAC Inc., Tokyo, Japan) operating at 250 Hz (exposure time 1/2000 s). Digitizing was manually conducted on computer software (DKH Inc., Tokyo, Japan). Body and racket 3-D coordinates were computed by the direct linear transformation (DLT) procedure developed by Abdel-Aziz & Karara (1971), and smoothed by using a Butterworth digital low-pass filter; cutoff frequencies determined by residual analysis proposed by Winter (1990) were 3-13Hz.

For kinematic analysis, the linear resultant velocity of the racket head and the absolute angles of the right upper extremity at impact were calculated. Then, using the approach of Winter (1990) and body segment parameters of Japanese athletes (Ae et al., 1992), the joint forces and torques of the right upper extremity were estimated solving Newton-Euler equation of motion. Fig. 2 shows joint reference frames attached at each joint center. R_S, reference frame attached at shoulder joint, consists of X_S (horizontal adduction (+) / abduction (-)), Y_S (adduction (+) / abduction (-)), Z_S (internal (+) / external (-) rotation); about R_E, reference frame at elbow, X_E (varus (+) / valgus (-)), Y_E (extension (+) / flexion (-)), Z_E (pronation (+) / supination (-)); about R_W, reference frame at wrist, X_W (ulnar- (+) / radial- (-) flexion), Y_W (palmar- (+) / dorsi- (-) flexion), Z_W (pronation (+) / supination (-)). However, to reduce subjects' sense of incongruity, subjects did not have markers at the distal end of the forearm, thus forearm pronation / supination were considered not to be estimated correctly. For the same reason, palmar- /dorsi-flexion and ulnar- / radial- flexion could not be distinguished precisely, thus wrist forces and torques along these two axes were composed as the "transverse" force and torque. Anatomical forces and torques were a projection of the resultant forces and torques on each axis of joint reference frame (R_S, R_E, R_W). Time origin is set at impact (T_{impact} = 0 (s)). Initiation of forward swing (IFS) was defined as the instant at which the racket head moves vertically upward relative to the center of body mass (including the racket mass). Calculated data were analyzed using a two-tailed paired t-test. The significance level for all analyses was 0.05.

RESULTS AND DISCUSSION: Time of IFS in the SS was T^{SS}_{IFS} = -0.129 ± 0.011 (s), in the JS T^{JS}_{IFS} = -0.118 ± 0.013 (s). T^{JS}_{IFS} is significantly later than T^{SS}_{IFS}. At impact, there was no significant difference in the resultant velocity of the racket head (SS: 34.0±3.1$m \cdot s^{-1}$, JS: 32.5±1.2 $m \cdot s^{-1}$). And all the joint angles of the upper extremity at impact did not show significant differences. This suggests that players impact the ball with similar posture of the upper extremity in both SS and JS. Fig. 3 shows the joint forces and torques of the SS of a typical subject. Since temporal tendencies of the joint forces and torques represented a few apparent differences between SS and JS, only the SS data are presented here. At impact, all anatomical forces and torques of the two techniques did not show any significant differences. In the following, the mean value of all SS and JS data is used as peak time in which no significant difference was seen. Regarding joint forces, the compressive force (+Z_S, Z_E, Z_W) near impact showed remarkable value at any joint. Going into details, the superior force (+X_S) at shoulder showed a peak at T = -0.135 ± 0.015 (s), followed by two anterior force (+Y_S) peaks at T = -0.119 ± 0.014 (s) and T = -0.032 ± 0.005 (s) (slightly weak). Then, near impact, the compressive (+Z_S) and inferior force (-Y_S) showed maximum value. At elbow, medial force (+Y_E) showed a peak at T = -0.116 ± 0.017, followed by an anterior force (+X_E) peak at T = -0.052 ± 0.009 (s), and this anterior force of JS was significantly larger than that of SS ($p < .05$; SS: 68.8 ± 26.4 N, JS: 91.7 ± 35.5 N). Near impact, the compressive (+Z_E) force came to maximum value. This peak of the elbow compressive force of JS was slightly but not significantly larger than that of SS ($p = .066$). At wrist, a transverse force peak at T = -0.060 ± 0.006 (s) and a weak compressive force (+Z_W) peak at T = -0.106 ± 0.009 (s) were observed. Both the transverse and compressive forces showed peaks near impact again. A wrist compressive force peak near impact of JS was slightly but not significantly larger than that of SS ($p = .070$).

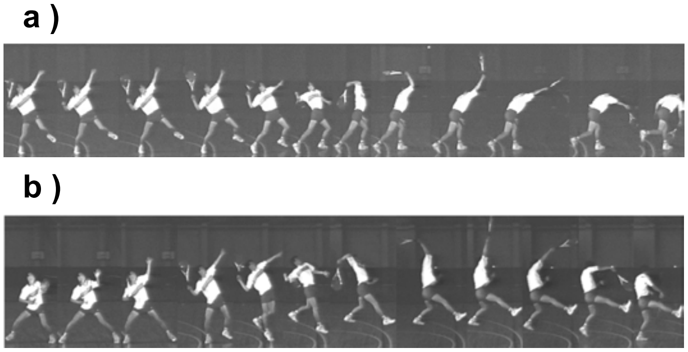

Figure 1 – a) standing smash, b) jumping smash.

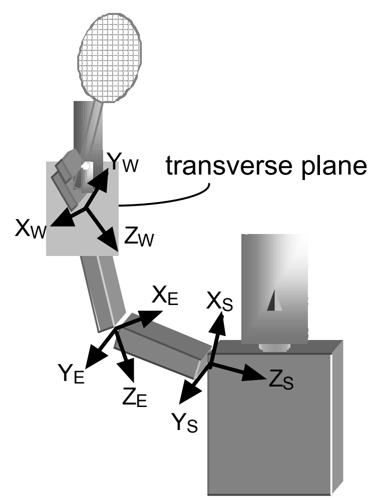

Figure 2 – Joint reference frames.

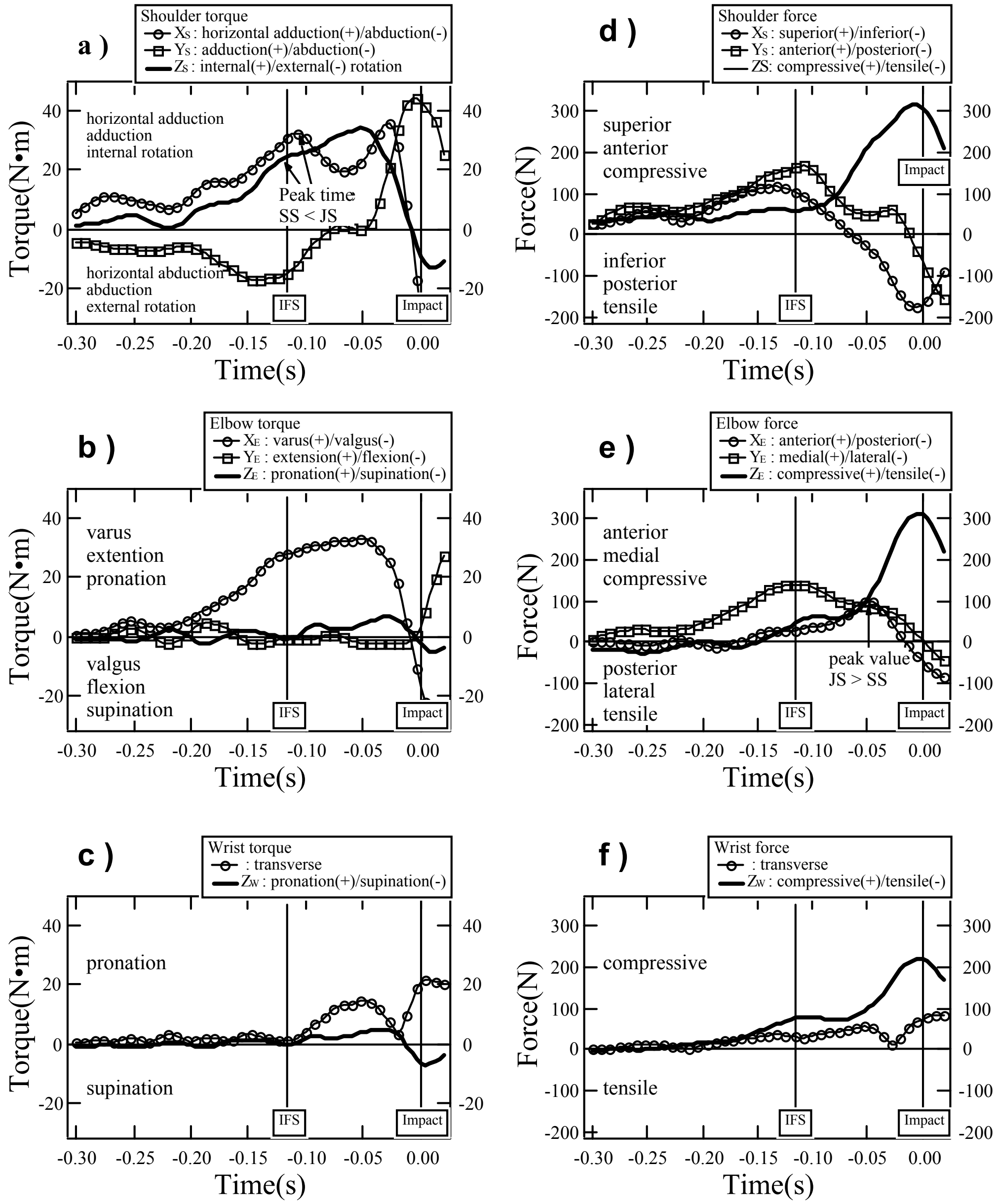

Figure 3 - Joint torques of a) shoulder, b) elbow, c) wrist, and joint forces of d) shoulder, e) elbow, and f) wrist of SS (typical subject).

As for joint torques, in general survey, the resultant torques at shoulder and elbow was comparatively large. At shoulder, the horizontal adduction torque ($+X_S$) showed two apparent peaks, though peaks of one subject were not completely separated. Time of one peak near IFS of JS (T = -0.095 ± 0.007 (s)) was significantly later than that of SS (T = -0.105 ± 0.012). About the internal rotation torque ($+Z_S$), peak was comparatively wide and decomposed into two small peaks for analysis. Similar to horizontal flexion, peak time before IFS of JS (T = -0.141 ± 0.010 (s)) was significantly later than that of SS (T = -0.158 ± 0.020). And, at first the abduction torque ($-Y_S$) was observed, followed by the adduction ($+Y_S$) torque showed maximum value near impact.

	smash techniques		
peak force near impact(N)	**SS**		**JS**
elbow anterior	68.8 ± 26.4*	<	91.7 ± 35.5*
elbow compressive	292.1 ± 37.3†		309.3 ± 35.7†
wrist compressive	189.9 ± 26.9†		203.5 ± 27.8†
time of torque peak near IFS (s)			
shoulder horizontal adduction	-0.105 ± 0.012*	<	-0.095 ± 0.007*
shoulder adduction	-0.158 ± 0.020*	<	-0.141 ± 0.010*
time of torque peak relative to IFS (s)			
shoulder horizontal adduction	0.024 ± 0.015		0.023 ± 0.018
shouder adduction	-0.029 ± 0.017		-0.023 ± 0.012
elbow varus	0.029 ± 0.013*	>	0.016 ± 0.017*

*p < .05, †p < .10

Table 1 – Remarkable Items as a Comparison Between SS and JS

At the elbow, the varus torque ($+X_E$) showed a large value during most of the forward swing and peak was comparatively wide, and changed to the valgus ($-X_E$) torque immediately before impact. The flexion/extension torque ($\pm Y_E$), absolute value was comparatively small and showed different tendencies between subjects. The pronation torque ($+Z_W$) showed peak, followed by the supination ($-Z_W$) torque immediately before impact, and near impact the supination torque showed maximum. The transverse torque also showed peak at T = -0.059 ± 0.010 (s) and came to maximum near impact. Time analyses were relative to impact. Only peak times of adduction and horizontal adduction near IFS at shoulder showed significance. These differences directly reflect the difference of IFS time. The peak time relative to IFS revealed different aspects of torque production. The shoulder torques did not show significance; at elbow, the peak time of the varus torque of JS was significantly nearer to IFS than that of SS. Although the varus torque peak appears near to IFS as the shoulder torques of adduction and horizontal adduction, time from this peak to the impact show no significance.

CONCLUSION: The racket head velocity and joint angles at impact did not show any significant differences. Similarity between the joint angles of the two techniques suggest that upper extremity posture at impact is not changed. Temporal tendencies of forces and torques were similar at both techniques. At impact, there were no significant differences of any anatomical forces and torques. However, on inspecting peaks, shoulder adduction and horizontal adduction torques of the JS showed a first peak, i.e. near IFS peak, later than that of SS. The peak time of the elbow and wrist forces did not show any significant differences relative to impact. However, relative to IFS, the peak time of the varus torque at elbow was significantly nearer to IFS. At shoulder, torques are considered to act in a relation to IFS; at elbow, the varus torque of both SS and JS act similarly relative to impact.

REFERENCES:

Abdel-Aziz, Y.I., Karara, H.M. (1971). Direct linear transformation from comparator coordinates into object space coordinates in close-range photogrammetry. *Proceedings of ASP/UI Symposium on Close Range Photogrammetry*, (pp. 1-18). Falls Church, VA: American Society of Photogrammetry.

Ae, M., Tang, H., & Yokoi T. (1992). Estimation of inertia properties of the body segments in Japanese athletes (in Japanese). *Biomechanisms*, **11**, 23-33.

Elliott, B., Marsh, T. and Blanksby, B. (1986). A three-dimensional cinematographic analysis of the tennis serve. *International Journal of Sports Biomechanics*, **2**, 260-271.

Feltner, M.E., and Dapena, J. (1986). Dynamics of the shoulder and elbow joints of the throwing arm during baseball pitch. *International Journal of Sports Biomechanics*, **2**, 235-259.

Winter, D.A. (1990). *Biomechanics and motor control of human movement*, 2nd ed. New York: John Wiley & Sons.