# KINEMATICS OF UPPER LIMB AND TRUNK IN TENNIS PLAYERS USING FOREHAND STROKE

Lin-Hwa Wang, Kuo-Cheng Lo[1], Hong Wen Wu[2], Fong-Chin Su
National Cheng Kung University, Tainan, Taiwan
[1]Kung Shan Institute of Technology, Tainan, Taiwan
[2]Foo Yin Institute of Technology, Kaohsiung, Taiwan

The purpose of this study is to investigate the three-dimensional kinematics of the upper limb during tennis. Six male national representatives performed a tennis forehand stroke in the laboratory. A motion analysis system was used to collect the motion trajectories of the shoulder, elbow, and wrist joints and the trunk. Two back swing techniques, multi-segment back swing and single-unit back swing, were compared. The results show that the multi-segment back-swing technique had larger elbow flexion velocity than single-unit back swing technique.

KEY WORDS: tennis, kinematics, upper limb, forehand stroke

INTRODUCTION: The forehand stroke of tennis is one of the basic techniques most frequently used. Through biomechanical analysis, the ranges of motion and movement skills in the chains of trunk, shoulder, elbow, and wrist joints will be completely understood to build an optimal pattern of tennis forehand stroke. Understanding three-dimensional joint movements of upper extremity based on the biomechanics and anatomy during forehand stroke of the tennis is important for tennis coaches and clinicians to prevent injuries. It also can provide a standard swing pattern of the upper extremity for tennis teaching in order to improve performance. The purpose of this study is to investigate the three-dimensional kinematics of the upper limb during tennis and effects of the back swing technique on joint motion.

METHODS: In the kinematic model, the trunk, upper arm, forearm, and hand were treated as a four-segment linkage system. For the spatial kinematic description, each segment was treated as a rigid body and each joint was assumed to be of the ball and socked type. Sixteen markers were placed on selected anatomic landmarks unilaterally to define the coordinate system of trunk, pelvis, upper arm, forearm and hand. The selected anatomic landmarks were processes xiphoideus, sternal notch, spinous process of the 7th cervical vertebra, acromion process, medial and lateral epicondyles of the elbow, radial and ulnar styloid processes, knuckle and knuckle V, anterior superior iliac pine, and posterior superior iliac pine. In addition, a triangular frame with three marks was placed on the upper arm. The positions of the markers on the medial and lateral epicondyle during tennis single-handed backhand drive were calibrated using the local vectors with respected to the triangular frame on the upper arm in an anatomical neutral posture. This was done in order to avoid error resulting from skin movements.

The rotation matrix used to describe the orientations of objects could be formulated based on these coordinate systems. The orientation of a distal segment coordinate system relative to a proximal segment coordinate system was used to describe the joint movement by

$$R_j = R_p^{-1} \times R_d$$

Where $R_j$ is the rotation matrix of joint movement in the global coordinate system and $R_p$ and $R_d$ are the rotation matrices of the proximal and distal segments.

To systemically describe the joint movements, the joint reference position was defined as that joint position that exists when the body is in the anatomical posture. The rotation of joint movement was modified as:

$$R = R_j \times ({}_0R_j)^T$$

Where R is the rotation matrix of joint movement based on the anatomical posture and ${}_0R_j$ is the rotation matrix of the joint reference position.

Euler angles were used to describe the orientation of a distal segment coordinate system relative to a proximal segment coordinate system. The first rotation about the y axis represents the flexion/extension angle $(\alpha)$. The second rotation about the x' axis represents the adduction/abduction angle $(\beta)$. The third rotation about the z" axis represents segmental axial rotation (y ).

EXPERIMENT: Six Taiwan male national representatives were recruited in this study. The ExpertVisionv™ system with six cameras (Motion analysis Corp., Santa Rosa, CA, USA) was used to collect the position of all reflective markers at 60 Hz while the subject performed tennis forehand strokes. Ten trials were sampled for each subject. Each trial lasted 5 seconds with 3 minutes rest between trials. The position of the markers were smoothed using a generalized cross-validation spline smoothing (GCVSPL) routine (Woltring, 1986) at a cutoff frequency of 6 Hz. A customed program in MATLAB language was written for the calculation of joint movements.

RESULTS AND DISCUSSION: Angular movements of the trunk, shoulder, elbow and wrist joints are shown in Figure 1. The results showed that the major movements of shoulder joint were abduction/adduction (69.3 ± 4.6°), flexion/extension (90.5 ± 11.6°), and internal1 external rotation (56.0±5.2°). The major movement of elbow was flexion/extension (46.9 ± 10.0"). The major movements of wrist were flexion/extension (50.7 ± 9.2") and radial/ulnar deviation (23.9" ± 8.8°). Observing angular velocity curves of joints in the upper limb, the calculated pattern was in accordance with the pattern of the real forehand drive. In other words, at the initial and the end of back swing, and the end of follow-through, the instantaneous velocities were nearly zero. The maximum angular velocity of flexion, internal rotation and adduction in the shoulder joint were about 3 radlsec, 3 radlsec and 2 rad/sec, respectively. The subjects had larger elbow flexion velocity using multi-segment back-swing technique than using single-unit back swing technique (Fig. 2). The maximum angular velocity in the elbow joint was 2.2 radlsec and 1 radlsec for multi-segment back-swing technique and single-unit back swing technique, respectively. The maximum angular velocities of right bending and left rotation were less than 1 radlsec.

CONCLUSION: Major motions in performing forehand stroke were adduction, external rotation and flexion in the shoulder joint, flexion/extension in elbow joint and wrist joint, and right/left axial rotation in the trunk. The rate of elbow flexion/extension velocity and its magnitudes are much greater while using multi-segment back-swing technique than using single-unit back swing technique. The elbow joint plays an important role while choosing multi-segment back-swing technique. The results may be helpful for sports physicians and therapists to improve the diagnosis of sports injury and the clinical treatments.

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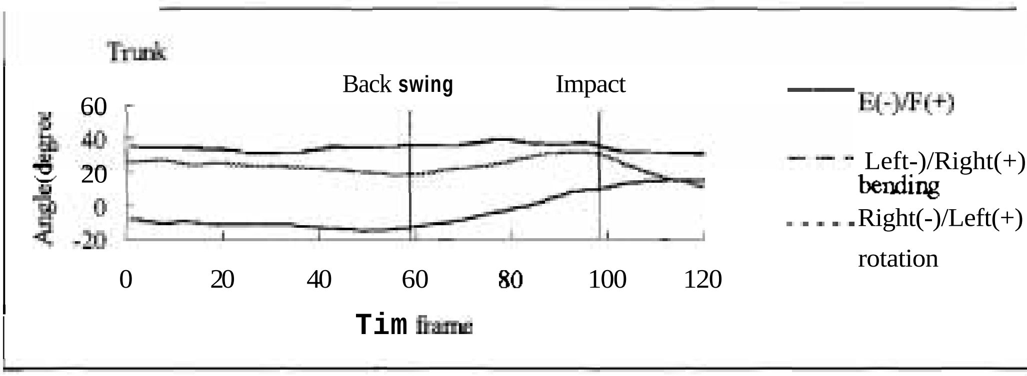


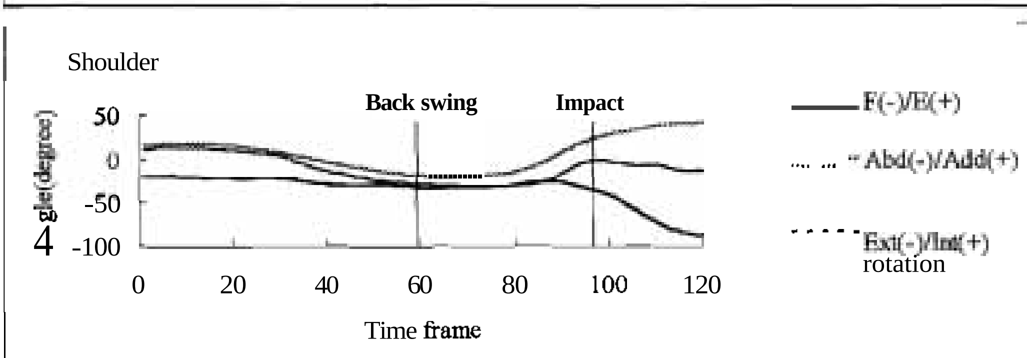


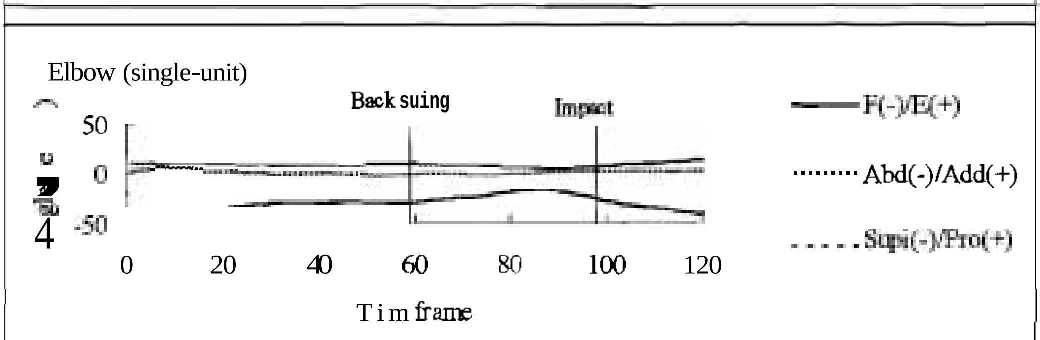

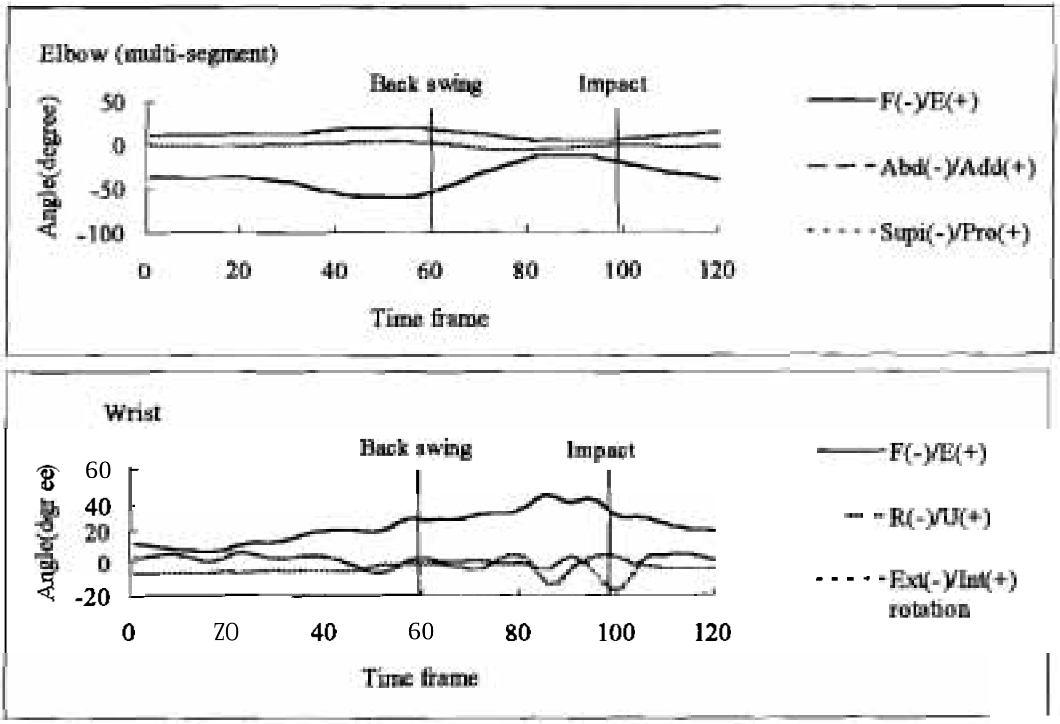


**Figure 1 - Joint movements of trunk, shoulder, elbow and wrist joints**

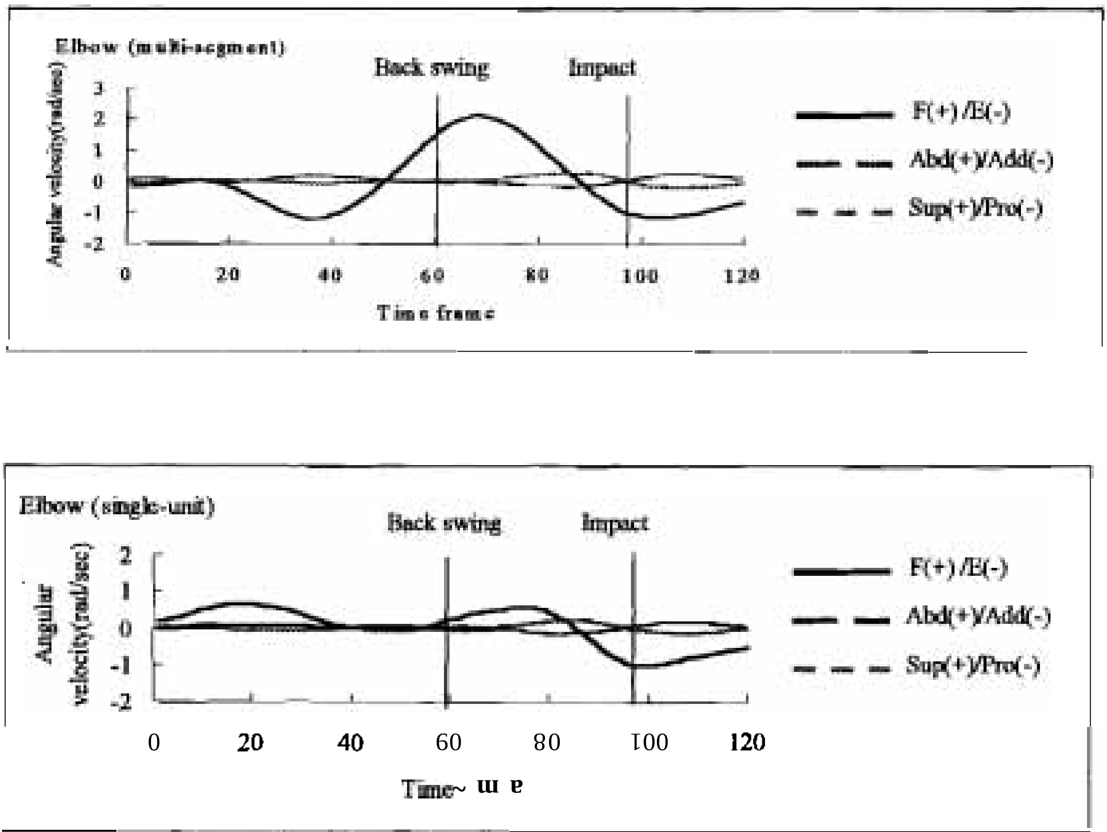


**Figure 2 - Joint angular velocity of the elbow joint using two different techniques**