BIOMECHANICAL ANALYSIS OF TRUNK & LOWER EXTREMITY IN TENNIS SERVE

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The purpose of this study was to explore the two different serving patterns---flat serve and spin serve, using a motion analysis system to discover the 3-D kinematic changes of the ankle, knee, hip, pelvis and trunk in the overall serving motion, in conjunction with force plates that helped to measure the ground reaction force (GRF) and worked out the center of pressure (COP). The moment formed by COP with the whole body center of mass would then be analyzed to explore the kinematic characteristics of the body. A further understanding of the role of joints in the lower extremity during a serve will provide a reference to motions and techniques on training and teaching, with a view to improve serving efficiency and avoid sports injury.

KEY WORDS: tennis, serve, kinematics, moment, COP, COM.

INTRODUCTION: The serve is one of the most important techniques in tennis. Tennis serve can generally be divided into three patterns: flat, spin, and slice. Tennis serve transfers the GRF to the trunk by tiptoeing of the lower extremity, utilizing an effective integrity of body segments and the continuity of limb motion from proximal end to distal end. Such a rotation plus a chain of mechanical effects of the customary arm will produce a "whipping motion" to complete the stroke.

Forceplates used to be applied to implement GRF-related study during the serve. Elliot and Wood (1983) used forceplates to compare the two techniques of foot-back and foot-up during the serve, and the results showed that foot-up used the effective momentum of the lower extremity, the vertical GRF was greater and impact point was higher. On the contrary, the horizontal GRF of foot-back was greater, and the first step for volley after serve was closer to the net. Van Gheluwe and Hebbelinck (1986) compared the influence of the three GRFs during the serve. The results showed that the horizontal reaction force was not obvious, but vertical reaction force was more obvious at the preliminary stage. The greatest force came from the vertical reaction, reaching 1/3 of body weight. Groppel (1984, 1992) pointed out that the transition of angular momentum from the GRF through body segment to the racket was the most unfamiliar concept in tennis research. Thus kinematics of the trunk in the tennis serve and GRF-related studies appeared to be important.

METHODS: Six elite male tennis players, all of whom are right-handed with many years of experiences on tennis singles and doubles and without any history of upper extremity symptoms, served as subjects. These subjects were on the best health condition when data were being collected, and used the same brand of rackets for the experiment. The HiRES Vision Motion System was used in the experiment. Six videos cameras were placed around the subjects at 120 Hz to collect trajectory image data of the subjects' limb motion during the serve. The subjects stood on two Kistler forceplates, with the frequency at 1000HZ, to measure and the GRF of feet during the serve. Before the experiment, calibration was required to work out the space coordinate system of the laboratory. The calibration procedures were as follows: place three cameras on each side of the subjects, and adjust their positions and aperture to have all the eight markers on the steel fixture captured by at least two cameras. Through the software of VCA and EVA, and input of the distance among the eight measured marks, the lab coordinate system could thus be built. In addition, another 21 markers were stuck on the players' main anatomical positions, such as styloid process of radius, lateral epicondyle, acromion, anterior superior ischial spine, mid-thigh-cuff with marker on wand, lateral knee plateau directly lateral to axis of rotation, mid-shank-cuff with marker on wand, lateral malleolous, heel, the 2nd & 3rd metatarsal head, and sacrum. The markers' position vectors were first collected as basic points when the subjects were standing, to modify the difference between the marker-defined coordinate system and anatomical coordinate system. Regarding the collection of dynamic image data, the subjects stood on two forceplates, one foot on one plate. After the trigger was launched, each subject executed a flat serve and a spin serve with two arms up. Each serving motion was collected 5 times for average value. The subjects performed the four phases of serve: throwing, racket drop, and wind-up-cocking-acceleration and impact-follow-through, 5-second period for each collection, with an interval of 3 minutes. Ten successful serves had to be collected from each subject.

RESULTS AND DISCUSSION:

Time parameter: The tennis flat serve and spin serve took 3.06 and 3.22 seconds, respectively. The spine serve took a little longer time than flat serve, without significant difference statistically. During the serve, most of the time was spent on throwing, impact, and racket drop. Acceleration period accounted for only 1/10 of the serve cycle.

3-D kinematic data of the lower extremity and trunk (see Figure 1): The major motions of the ankle for both flat serve and spin serve are dorsiflexion and plantaflexion. Initially, the left foot had a slight plantaflexion for 5 degrees, then had a flexion towards dorsiflexion during mid-racketdrop, and reached the maximum of 18-degree dorsiflexion during acceleration. Next, the foot produced a "tiptoe" towards plantaflexion. On the other hand, the right foot had been on the condition of 5-degree dorsiflexion from the beginning, and would reach the maximum of 10-degree dorsiflexion during during acceleration, then produced a "tiptoe" towards plantaflexion, and reached the maximum of 20-degree plantaflexion before impact.

The major motions of the knee for both flat serve and spin serve are flexion and extension. At the beginning, the knees did not bend; however they started to bend at mid-racketdrop, and reached the maximum during acceleration. At this moment, the largest flexion angle of the spin serve was approximately 50 degrees, and the largest bend angle of the flat serve was 30 degrees. In other words, the spine serve bent the lower extremity more often than the flat serve. The lower extremity would straighten back before impact.

During the entire serving cycle, the hip bent all the way, and only straightened to 0 degree before impact, and bent again immediately. At the beginning, the left foot abducted 20 degrees, and started to adduct at mid-racket drop, reaching the maximum of 10-degree abduction during acceleration, then started to abduct. The right foot maintained natural from the beginning, then started to abduct at mid-racket drop, and reached the maximum of 15-degree abduction, then started to adduct.

The pelvis at the beginning rotated externally, and did not start to rotate internally until acceleration. The difference between the flat serve and spin serve was the more backward pelvis tilting on spin serve during acceleration, reaching approximately 0 degree and 5-degree backward tilting.

The trunk at the beginning rotated externally. In dorsiflexion, the trunk reached the maximum before impact, around 25 degrees for the spin serve, and 18 degrees for the flat serve. In right-side bend, the trunk reached the largest angle at the end of acceleration for both serves, 25-degree right-side bend, and then went on left-side bend.

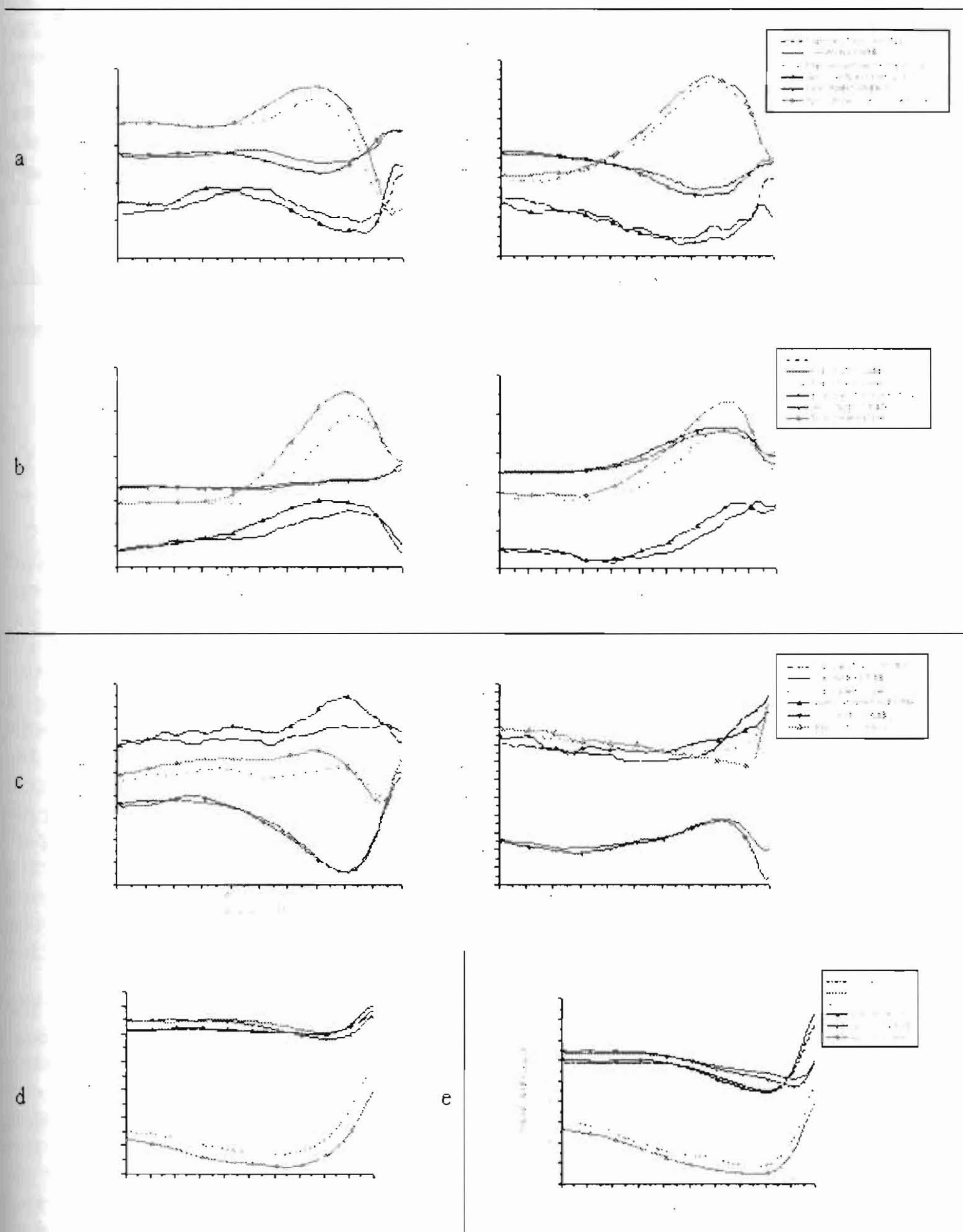

Figure 1: 3-D kinematic data of the lower extremity and trunk.

CONCLUSION: From the data of 3-D kinematics of the lower extremity and trunk and body moment, we can see that the spin serve produces more lateralflexion moment than flat serve, and this moment comes mainly from the lateralflexion of the trunk. This point can be verified by the 3-D kinematics results of the trunk. In addition, in the data of 3-D kinematics, the spin serve has a significant difference from the flat serve: the former produced more knee bend than the latter during acceleration, and more backward pelvis tilting. This will help to increase the momentum during the serve and its transfer. From this study, we can further understand the role of joints in the lower extremity during a serve will provide a reference to motions and techniques on training and teaching, with a view to improve serving efficiency and avoid sports injury.

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