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RELATIONSHIP BETWEEN JOINT TORQUE OF SUPPORT LEG AND GROUND REACTION FORCE IN SIDE-STEP CUTTING

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The purpose of this study was to investigate the relationship between the joint torque of the support leg and the ground reaction force in the side-step cutting technique. The ground reaction forces and three-dimensional kinematics of the side-step cutting motion with 90° direction change were collected from 20 male university ball-game players. The angular impulses of the knee and ankle extension torques were correlated with the impulses of the inward, backward, and forward ground reaction forces. These results indicate that the knee and ankle contributed to change the horizontal velocity of the center of mass. Although the angular impulses of the hip joint did not correlate with the impulses of the ground reaction forces, the hip exerted large extension and adduction torques immediately after the foot strike. This implies the hip contributed to maintain the body's position and balance rather than to change the velocity of the center of mass.

KEY WORDS: 3D motion analysis, center of mass, inverse dynamics

INTRODUCTION: The cutting motion used to change the running direction is one of the most important techniques for ball-game players. Although there are some techniques in the cutting motion, the side-step cutting technique is one of the most commonly used techniques in ball-game players. To change the direction and magnitude of the velocity of the center of mass (CM), a player applies force to the ground by exerting joint torque in the support leg. There are some studies on the kinetics of the support leg in the cutting motion concerning the risk of leg injuries (McLean et al., 2005; Sigward and Powers, 2007), but it is unclear how the support leg joints contribute to change the magnitudes and direction of the CM velocity in the side-step cutting. Understanding the relationship between the joint torques of the support leg and the ground reaction forces and the function of the support leg joints helps to design appropriate training programs for improvement in cutting performances.

The purpose of this study was to investigate the relationship between the joint torque of the support leg and the ground reaction force in the side-step cutting technique.

METHODS:

Twenty male university players of soccer, basketball, rugby, and handball (age, 20.3 ± 0.8 yrs; height: 1.76 ± 0.06 m; body mass: 73.15 ± 7.69 kg) participated in this study. Subjects performed at least three trials for 90° cutting direction with the side-step technique (Figure 1). Electric timing devices with photocell sensors were set 3 m from the center of a Kistler force platform (9287B, Kistler Instrument AG) to monitor running time. They started at the 10 m line from the center of a force platform and ran through the finish line. Subjects were asked to step on the force platform with a right foot and run through the timing area as fast as possible. Three-dimensional coordinate data of 47 retro-reflective markers fixed on the subjects

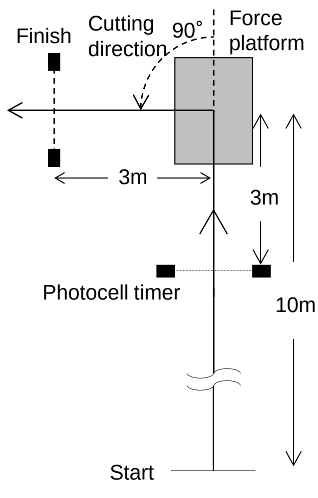

Figure 1: The experiment setup and the cutting direction.

body and the ground reaction force data were captured with a Vicon T10 system (Vicon Motion Systems, Ltd., 250Hz) and a force platform (1000 Hz). These data were time-synchronized for subsequent inverse dynamics analysis. One trial with the shortest running time was selected for each subject as a successful trial for detailed analysis. The coordinates and ground reaction forces were smoothed by a Butterworth digital filter with optimal cut-off frequencies ranging from 7.5 to 12.5 Hz for the coordinates and from 20 to 45 Hz for the ground reaction forces, which were determined by the residual method (Winter, 2004).
The CM coordinates were estimated after the body segment parameters of Japanese athletes (Ae, 1996) and then differentiated for the velocities of the CM. The direction change angle was defined as the angle between the horizontal velocity vectors of the whole-body CM at the foot strike and at the toe-off. The cutting motion was divided into two phases as the deceleration phase (from the foot strike to the instant of minimum horizontal velocity of the CM) and the acceleration phase (from the instant of minimum horizontal velocity to the toe-off).
Since the direction of the horizontal velocity of the whole-body CM in the cutting motion continued to change throughout the support phase, the ground reaction forces were transformed to the local coordinate systems fixed to the whole-body CM. In this transformation, the Y' axis as the forward/backward axis was defined along the direction of the horizontal velocity of the whole-body CM, and the X' axis as the inward/outward axis was defined as the cross product of the Y' and Z (vertical) axes. The joint torques of the support leg were calculated using an inverse-dynamics approach with a three-rigid-segments model consisting of the foot, shank, and thigh of the support leg. The equations of motion for these segments were solved from the distal to proximal segments by using the ground reaction forces and center of pressure location data as inputs for the equations.
Pearson's correlation coefficients were calculated on the relationships between the angular impulse of the joint torques and the impulse of the ground reaction force with the significant level set at 5%.

RESULTS: The horizontal CM velocity at the foot strike, 3.82 ± 0.28 m/s, decreased during the deceleration phase by -0.63 ± 0.23 m/s, and then increased toward the toe-off by 0.43 ± 0.12 m/s.
Figure 2 shows the averaged patterns of the inward/outward, backward/forward, and vertical ground reaction forces. The inward/outward component was negative (inward) throughout the

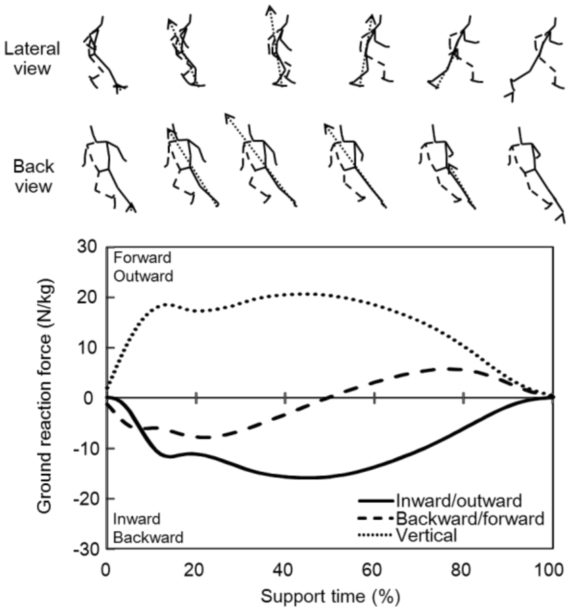

Figure 2: Averaged patterns of the inward/outward, backward/forward, and vertical ground reaction forces.

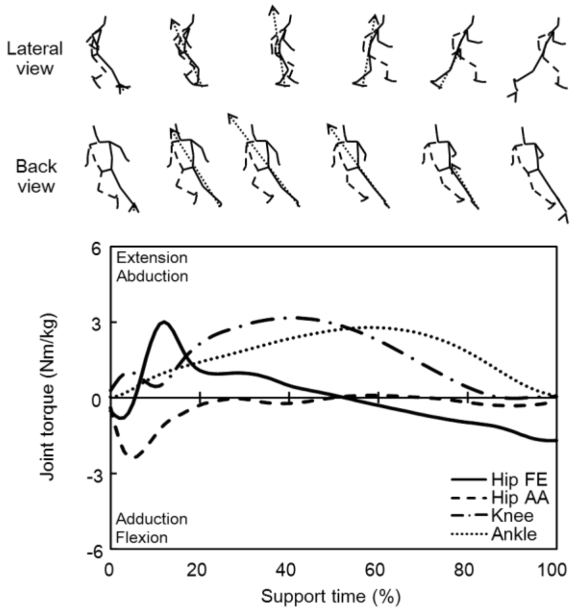

Figure 3: Averaged patterns of the hip flexion/extension (FE) and adduction/abduction (AA), knee flexion/extension, and ankle dorsiflexion/plantarflexion torques.

support phase, with peaking about 50% support time. The backward/forward component was negative (backward) during the deceleration phase and then positive (forward) until the toe-off.

Figure 3 presents the averaged patterns of the hip flexion/extension, hip adduction/abduction, knee flexion/extension, and ankle dorsiflexion/plantarflexion torques. The hip exerted the large extension torque after the foot strike and flexion torque before the toe-off. For adduction/abduction, the hip exerted adduction torque immediately after the foot strike but the hip did not exert large adduction/abduction torque in the rest of the support phase. The knee and ankle exerted extension and plantarflexion torques throughout the support phase, with peaking about 40% and 60% support time, respectively.

Table 1: Correlation coefficients between the angular impulses of the hip flexion/extension (FE) and adduction/abduction (AA), knee, and ankle joint torques and the impulses of the inward, forward/backward, and vertical ground reaction forces.

	Hip FE	Hip AA	Knee	Ankle
Deceleration phase				
Backward	-0.277	0.289	-0.695*	-0.551*
Inward	-0.276	0.401	-0.688*	-0.594*
Vertical	0.141	-0.353	0.746*	0.535*
Acceleration phase				
Forward	-0.137	0.369	-0.736*	-0.873*
Inward	0.210	-0.379	0.731*	0.916*
Vertical	0.151	-0.384	0.790*	0.921*

*: $p<0.05$

Table 1 indicates correlation coefficients between the angular impulses of the hip, knee, and ankle joint torques and the impulses of the ground reaction force. In the deceleration phase, there were significant negative correlations between the knee and ankle angular impulses and the impulses of the inward and backward ground reaction forces. However, there was no significant correlation between the hip angular impulses and the impulses of the ground reaction force. In the acceleration phase, the knee and ankle angular impulses negatively correlated with the impulse of the inward ground reaction force and positively correlated with the impulse of the forward ground reaction force.

DISCUSSION:

Neptune et al. (1999) and Rand and Ohtsuki (2000) found that the eccentric contraction of the knee extensors contributed to the deceleration of the CM in the braking phase, and the concentric contraction helped accelerate the body in the propulsive phase in the cutting motion. The results of the present study and previous studies indicate that the knee and ankle contributed to change the magnitude of horizontal CM velocity in the side-step cutting.

It was expected that the hip abduction torque would be exerted to increase the inward ground reaction force, and to change the direction of the CM velocity. However, the hip exerted large adduction torque immediately after the foot strike, and the angular impulses of the hip joint did not correlate with the impulses of the ground reaction force during the support phase. When the foot settled down the ground in the side-step cutting motion, players leaned the body inward about the foot placed in front of the body so that the flexion and abduction moments by the ground reaction forces were applied to the hip joint. Therefore, the hip exerted the extension and adduction torques to prevent the hip joint from collapsing and excess inward lean of the support leg immediately after the foot strike. Both in deceleration and acceleration phases, the impulse of the inward ground reaction force was significantly correlated with the angular impulses of the knee and ankle extension torques. The inward ground reaction force peaked about 50% support time, and the knee and ankle exerted large extension torque in the mid-support. These results indicate that the knee and ankle contributed to increase the inward ground reaction force with the body leaning inward.

CONCLUSIONS: The knee and ankle exerted extension torques throughout the support phase. The angular impulses of the knee and ankle joints were correlated with the impulses of the inward, backward, and forward ground reaction forces. These results indicate that the knee and ankle contributed to change the magnitude and direction of the horizontal CM velocity. Although the angular impulses of the hip joint did not correlate with the impulses of the ground reaction forces, the hip exerted large extension and adduction torques immediately after the foot strike. This implies the hip contributed to maintain the body's position and balance rather than to change the CM velocity.

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