COMPARISON BETWEEN GROUND REACTION FORCE PATTERNS AND ANGULAR, APPROACH, AND BALL VELOCITIES FOR IN-STEP KICKING

Heidi Orloff, Lahlae Habibi & Brian Kramer

University of Puget Sound, Tacoma, Washington, USA

The purpose of this study was to determine if patterns in vertical ground reaction forces resulted in differences in hip, knee and trunk angular velocity and efficiency of the open kinetic chain. 20 subjects performed a maximal in-step kick while ground reaction forces of the plant leg, as well as angular, approach and ball velocities were recorded. Although approach and ball velocity did not change between groups, the decreasing vertical force group had significantly higher initial peak vertical ground reaction forces and angular hip velocities than subjects with a double vertical peak pattern. There was a significant relationship between approach velocity and ball velocity, as well as a negative relationship between posterior lean on contact and leg angular velocity. It seems that the pattern of vertical force with the plant leg is not a key factor in ball velocity.

KEY WORDS: angular momentum, soccer kicking, ball velocity.

INTRODUCTION:

Soccer is a popular sport that involves powerful movements such as running, cutting, and kicking. In a kicking movement, the swinging leg gains momentum by functioning as an open kinetic chain in which the angular momentum, caused by torque of the slow moving but massive trunk, transfers from the hips to the knees (Kreighbaum and Barthels, 1996). In this chain, the leg swings back with extension of the hip joint and flexion of the knee. After the loading phase, the hip accelerates while the knee is still flexed. The hip then begins to decelerate, transferring momentum from the thigh to the lower leg. Energy from the kicking foot is then transferred to the soccer ball through contact, resulting in ball velocity (Lees and Nolan, 1998).

During in-step kicking, the plant leg orients the player to the ball and serves as the axis of rotation for the swinging leg (Barfield, 1998). How the body loads on the plant leg can affect the kinetic chain, as velocity of the approach and resulting ground reaction forces contribute to the initial momentum for the kick (Isokawa & Lees, 1988). Differing initial ground reaction forces, particularly in the vertical and anterior/posterior plane of motion, could affect the transfer of momentum from the trunk to the kicking leg. The purpose of this study was to determine if patterns in vertical ground reaction forces resulted in differences in hip, knee and trunk angular velocity and efficiency of the open kinetic chain.

METHOD:

This study was approved by the University of Puget Sound Institutional Review Board. Experimental procedures were explained to 20 apparently healthy NCAA Division III college age male (n=11) and female (n=9) soccer players and consent was obtained to participate in the study. Mean height and weight for the males was 1.81$\pm$.22 m and 81.2$\pm$6.7 kg, while the females mean height was 1.57$\pm$.18 m and weight was 66.2$\pm$7.2.

The subjects completed a 5 minute warm-up on a cycle ergometer set to light resistance. Prior to testing, each subject performed a self-directed warm-up by jogging, stretching, and passing the soccer ball. As part of the warm-up, subjects performed 3-5 practice trials in the lab to acquaint themselves with the testing equipment and the kicking conditions. Subjects were instructed to kick the ball with maximum effort. The subjects placed the ball in a self-selected location, which allowed the subject to plant his/her foot on the center of the force plate. The subject proceeded to kick the ball into a net while digital video and force data were collected. The subject performed as many kicks necessary until he/she was satisfied that a maximal performance was recorded.

All kicks were performed on an AMTI 1000 force plate set to sample at 600 Hz. The force plate was covered with artificial turf to simulate playing conditions. SIMI® Motion (v6.2) was used to digitize the video data collected at 60 Hz from the sagittal view. The shoulder, hips, knees, ankles, heels, and fifth metatarsal, as well as the ball were marked for digitization. The trunk, hip and knee angular velocity were recorded during the swinging phase of the kicking leg. Trunk angle was calculated as an absolute angle to the vertical-axis, while knee and hip angles were relative angles. Approach velocity of the body was recorded just prior to contact of the plant foot with the force plate, while ball velocity was calculated in the five frames after ball contact. Force curves were recorded in the vertical, anterior/posterior, and medial/lateral axes of motion. One way analysis of variance was used to compare the three vertical force pattern groups across discrete variables ($\alpha<.05$). Correlation was calculated between ground reaction forces and angular, approach and ball velocities ($\alpha<.05$).

RESULTS:

The three distinct vertical force patterns that were observed can be found in Figure 1. The first pattern exhibited an initial high force with a lower force recorded just prior to contact (decreasing vertical GRF). There were 6 women and 1 man with this pattern. The second pattern, which consisted of 4 women and 3 men, had two distinct vertical force peaks (double vertical GRF), while the third pattern had a lower initial vertical peak force with an increase in force just prior to contact (n=6 males) (increasing vertical GRF). The declining vertical GRF pattern had significantly more hip peak angular velocity and vertical peak force than the double vertical GRF pattern group. Just prior to ball contact vertical force was significantly lower for the decreasing vertical GRF pattern than for the other two patterns (Table 1). Ineffectiveness in kinetic chaining was noted in 6 subjects (firing the joints out of order or a lower knee angular velocity than at the hip or trunk), two in each pattern group.
Correlation coefficients (Table 2) showed a significant, but moderate, negative correlation between anterior/posterior peak force and hip (-.49) and knee (-.45) angular velocity. Ball velocity was related significantly to knee angular velocity (.45) and approach velocity (.72).

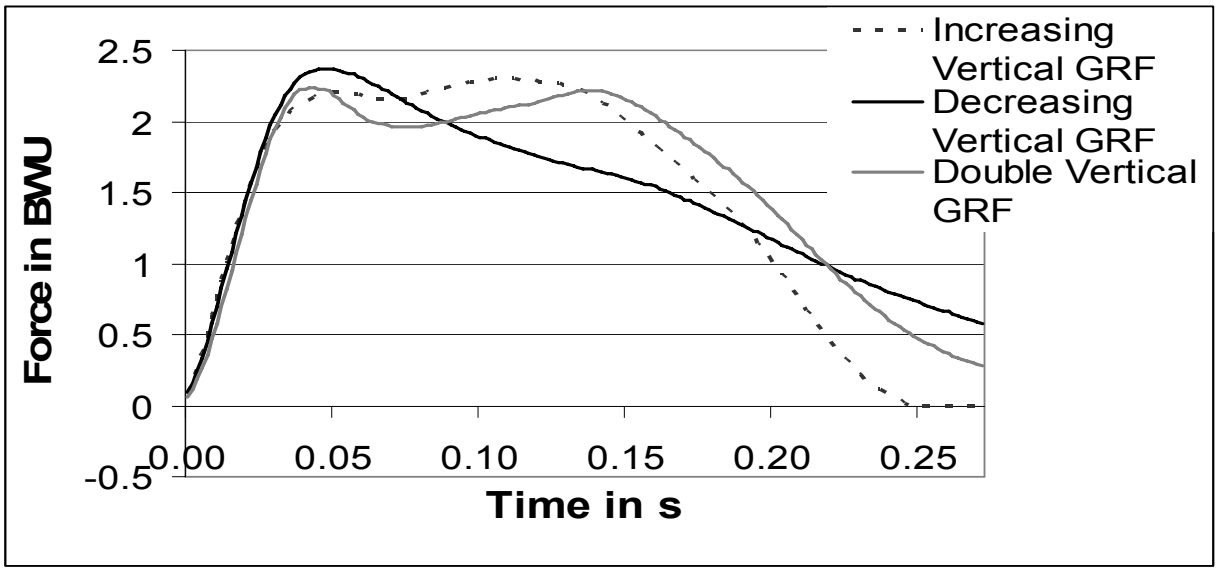

Figure 1: Three distinct patterns of vertical GRF

Table 1 Mean (SD) ground reaction forces, as well as angular, approach and ball velocities

	Declining Vertical GRF Mean (SD) n=8	Double Vertical GRF Mean (SD) n=6	Increasing Vertical GRF Mean (SD) n=6
Hip °/s	896 (±156)*	697 (±154)*	806 (±146)
Trunk °/s	307 (±137)	277 (±100)	270 (±61)
Knee °/s	1237 (±435)	1109 (±446)	1229 (±340)
Approach v m/s	3.70 (±.66)	3.38 (±.40)	3.63 (±.34)
Ball v m/s	22.18 (±3.75)	21.62 (±2.64)	21.90 (±3.42)
Vertical Peak Force BWU	2.59 (±.43)*	2.20 (±.17)*	2.25 (±.12)
Vertical Force prior to contact BWU	1.42 (±.59)^	2.14 (±.23)^	2.06 (±.56)^

* decreasing vertical GRF significantly different from double vertical GRF (α<.05)
^decreasing vertical GRF significantly different from double & increasing vertical GRF (α<.05)

Table 2 Correlation coefficients between ground reaction forces and angular, approach and ball velocities

	Peak Vertical GRF	Prior to Contact Vertical GRF	Anterior/Posterior Peak GRF	Medial/Lateral Peak GRF	Ball Velocity
Hip Joint Velocity	.41	-.30	-.49*	.17	-.12
Trunk Velocity	.36	.06	-.39	-.01	-.05
Knee Joint Velocity	.39	.09	-.45*	.41	.45*
Approach v	.25	-.08	-.32	-.05	.72*
Ball v	.42	.14	-.41	.08	

*significant at (α<.05)

DISCUSSION:

The three patterns of vertical ground reaction force for the plant leg were very distinct. In the decreasing force pattern subjects tended to have a high initial peak vertical force and failed to maintain the force values to ball contact. This pattern was typified by high velocity of hip angular acceleration of the kicking leg, but significantly lower vertical force just prior to contact. It appeared that these subjects relied on the initial peak vertical force to generate ball velocity while the other two patterns relied on more efficient kinetic chain measures to generate ball velocity. It was expected that if the initial peak vertical forces for the decreasing pattern were higher, the approach velocity would also be significantly higher for this group (Lees & Nolan, 1998). Although approach velocity was higher it was not significantly higher, this was further emphasized by the weak correlation between approach velocity and peak vertical ground reaction force.

The double vertical peak pattern had lower hip angular velocity and initial peak vertical force, but the vertical force just prior to contact was significantly higher than for the decreasing pattern. It seemed that this group was better at maintaining vertical force from foot contact until the kick occurred, needing less angular velocity at the hip and knee to generate ball velocity. Segmental dynamics can determine success in kicking, without regard to plant leg forces (Nunome et al., 2006). The third pattern of increasing vertical force over the duration of the plant foot contact with the ground until ball contact seemed efficient in that the body had to endure lower initial forces and might have relied on muscle forces to generate ball velocity.

It was expected that one pattern of vertical force would produce higher ball velocity. This was not the case, as there were no significant differences between the three patterns in ball velocity or approach velocity. It appears that more than one pattern can lead to the same results in this case. Kellis, Katis & Gissis (2004) found that approach angle to the ball changed medial and posterior ground reaction forces. Neither medial nor posterior forces were significantly different in the three groups in this study, but posterior forces were negatively correlated with hip and knee angular velocity. The farther back the kicker was

leaning on contact the slower the leg velocity. Although significant, the correlation is only moderate and should be viewed with caution, as should the knee joint velocity. On the other hand, approach velocity was strongly correlated with ball velocity. This was expected, as other authors have established this high correlation in the past (Barfield, Kirkendall & Yu, 2002; Lees & Nolan, 1998).
Most researchers have found that differences in ball velocity do occur between the genders (Barfield, Kirkendall & Yu, 2002). This was not the case in this study, as there were no significant differences in either ball velocity after contact or approach velocity of the kicker. Subjects were not segregated based on gender, due to these initial findings, in this paper.

CONCLUSION:

High initial peak vertical force and angular velocity at the hip did not result in higher ball velocity, but approach velocity is positively related to ball velocity.

REFERENCES:

Barfield, W. Biomechanics of kicking in soccer. (1998). *Clinics in Sports Medicine*, 17(4): 711-28.

Barfield, W., Kirkendall, D., Yu, B. (2002). Kinematic instep kicking differences between elite female and male soccer players. *Journal of Sports Science and Medicine*, 1, 72-79.

Dorge, H., Andersen, T., Sorensen, H., Simonsen E. (2002). Biomechanical differences in soccer kicking with the preferred and the non-preferred leg. *Journal of Sports Sciences*, 20, 293-299.

Isokawa, M., Lees, A. (1988). A biomechanical analysis of the instep kick motion in soccer. In T. Reilly, A. Lees, K. Davids, and W. Murphy (eds.), *Proceedings of Oral Sessions, Science and Football* (pp.449-455), London: E. & F.N. Spon. Reilly, A. Lees, K. Davids, and W Murphy (eds.), *Proceedings of Oral Sessions, Science and Football* (pp. 449-455), London: E. & F.N. Spon.

Kellis, E., Katis, A., Gissis, I. (2004). Knee biomechanics of the support leg in soccer kicks from three angles of approach. *Medicine and Science in Sports and Exercise*, 6, 1017-1028

Kreighbaum, E., Barthels, K. (1996). *Biomechanics: A Qualitative Approach for Studying Human Movement*. Needham Heights, MA: Allyn and Bacon.

Lees, A., Nolan L. (1998). The biomechanics of soccer: A review. *Journal of Sports Sciences*, 16, 211-234.

Nunome, H., Ikegami, Y., Kozakai, R., Apriantono, T., Sano, S. (2006). Segmental dynamics of soccer instep kicking with the preferred and non-preferred leg. *Journal of Sports Science*, 24(5), 529-541.

Acknowledgement
This study was funded by a University of Puget Sound Research Grant. The authors wish to thank Weston Wood, Bryce Sumida and Janna Chow for their contributions to the work completed.