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Research article

KINEMATIC INSTEP KICKING DIFFERENCES BETWEEN ELITE FEMALE AND MALE SOCCER PLAYERS

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ABSTRACT
The rapid rise in female participation in soccer worldwide has not been followed by a corresponding increase in the number of studies biomechanically that target female kicking patterns to determine if differences exist between males and females. The objectives of this study were to examine kinematic instep kicking differences between elite female and male soccer players in dominant and nondominant limbs. Eight elite soccer players, six females and two males, volunteered as subjects in the study. Subjects took a two-step angled approach of 45-60 degrees to a stationary soccer ball positioned between two force platforms and kicked the ball with the instep portion of the foot as hard as possible into netting which was draped from the ceiling. Ball velocity was the dependent variable. We evaluated six additional variables that have previously been shown to be important predictors of instep kicking ball speed. The males generally kicked the ball faster than the females and displayed greater kinematic variables, including maximum toe velocity, ball contact ball velocity, mean toe velocity, mean toe acceleration, and ankle velocity at ball contact, all of which contributed to faster ball speed. There was one exception. One of the elite females kicked faster than the two elite males and demonstrated higher or similar kinematic patterns when compared with the males. Our conclusions were that females do not instep kick the ball as fast as males, but there are exceptions, as our data demonstrates.

KEY WORDS: Soccer kicking, biomechanics, gender differences.

ERKEK VE KADIN FUTBOLCULAR ARASINDA AYAK ÜSTÜ İLE TOPA VURMA KİNAMATİĞİ FARKLILIKLARI

ÖZET
Evrensel futbola katılan kadınların hızlı artışı, erkekle kadınlar arasında bir farklılık olup olmadığı konusunda kadınların topa vurma modellerini inceleyen biomekaniksel çalışmaların sayısında benzer bir artış göstermemiştir. Bu çalışmanın amacı elit kadın ve erkek futbolcularda dominant ve non-dominant bacaklarda ayak üstü ile topa vurma kinematiği farklılıklarını incelemekti. Sekiz elit futbolcu (6 erkek ve 2 kadın) bu çalışma için gönüllü oldu. Denekler iki kuvvet platformu arasında duran topa 45-60 derecelik açı ile iki adım aldı ve topa ayağın üst bölümü ile çatıdan salınmış ağın içine doğru olabildiğince kuvvetli bir şekilde vurdu. Top hızı bağımlı değişkendi. Daha önce ayak üstü ile vurma top hızını tahmin etmede önemli kabul edilen altı ek değişkeni de değerlendirdik. Genellikle erkekler, kadınlardan daha hızlı bir şekilde topa vurdu ve

maksimum ayak parmak hızı, topla temas top hızı, ortalama ayak parmak hızı, ortalama ayak parmak hızlanması (ivmelenmesi), topla temasta ayak bileği hızı gibi daha hızlı top hızı ile ilgili olan kinematik değişkenleri daha büyük olarak gösterdi. Bir istisna vardı. Elit kadınlardan biri iki elit erkekden daha hızlı topa vurdu ve erkeklerle karşılaştırıldığında daha yüksek veya aynı kinematik modeller gösterdi. Bizim kararımız, kadınlar erkekler kadar hızlı ayaküstü ile topa vuramaz. Fakat bizim bulgularımızın gösterdiği kadarı ile istisnalar var.

ANAHTAR KELİMELER: Futbolda topa vurma, biomekanik, cinsiyet farklılıkları.

INTRODUCTION

In the sport of soccer, instep kicking (IK) is one of the most fundamental and frequently used skills. In mature, skillful, soccer athletes the instep kick involves a complex interaction of angled approach to the ball, subsequent support foot contact (SFC) with the ground accompanied by sequential transfer of momentum from proximal to distal body segments in the swing or kicking limb. Following the angled approach the support foot is placed alongside and adjacent the ball with the toe of the support foot pointed in the intended direction of ball movement. The kicking limb at SFC is in a position of hip extension, knee flexion and ankle plantar flexion. In powerful IK, following preparation of the kicking limb, the hip is forcefully flexed and the knee is sequentially extended so that forces generated can be channeled into propelling the ball. At ball/foot contact powerful kickers keep the foot/ankle complex locked and tightly plantarflexed so forces for propelling the ball can be maximized (Chyzowych, 1979; Hay, 1996; Tsaousidis and Zatsiorsky, 1996).

Studies in the literature on the biomechanics of instep kicking have focused on numerous variables in different populations, all seeking to establish the optimal variable or variables that might be most predictive of success in instep kicking, with success being most typically defined by resultant ball velocity. Instep kicking has been studied from the youngest age groups to seasoned professionals (Asai et al., 1980; Asami and Nolte, 1983; Barfield, 1993; Barfield, 1995; Barfield, 1997; Bloomfield et al., 1994; Butterfield and Loovis, 1994; Elliott et al., 1980; Kaufmann et al., 1975; Luhtanen, 1988; Narici et al., 1988; Olson, 1985; Plagenhoff, 1971), and there is general agreement that elite athletes exhibit less mechanical variability and greater temporal proximity of the kicking movement components compared with novice or unskilled athletes (Abo-Abdo, 1981; Ben-Sira, 1980; Chyzowych, 1979; Dos Angos and Adrian, 1986; Gainor et al., 1978; Hay, 1996; Nishijima et al., 1996; Rodano and Tavana, 1993; Phillips, 1985; Tsaousidis and Zatsiorsky, 1996).

The primary factors, influencing swing limb velocity are hip rotation followed by hip flexion and knee extension prior to ball contact (BC). Transfer of momentum from the thigh to the leg is believed to play an important role in instep kicking, yet these claims have not been conclusively quantified (Dunn and Putnum, 1988; Huang et al., 1982; Lindbeck, 1983; Roberts and Metcalfe, 1968; Robertson and Mosher, 1985). The summation of speed principle cannot be totally supported with research (Putnam, 1991) primarily because the complexity of instep kicking motion is a multiplanar movement and the motion of a single segment within a linked system is nonlinear and cannot be solely attributed to muscle forces and moments acting on that one segment. Because instep kicking is a complex movement individual segmental role quantification is difficult to measure.

There is limited research on instep kicking differences between dominant and nondominant sides, and the growth in female soccer has failed to lead to a corresponding growth in the study of female kicking patterns. Empirically mechanical differences exist between dominant and nondominant side instep kicking and between the genders, however there are no known studies of this principle skill among elite level female soccer players. Therefore, our investigation was to examine selected kinematic differences between elite female and male soccer players in instep kicking with dominant and nondominant limbs. Our hypotheses were that males using the instep would kick the ball faster than females and would generally exhibit larger kinematic variables in the swing limb, leading to greater resultant ball velocity when compared with elite females.

METHODS

Eight elite soccer players, six females and two males, volunteered to be subjects. All females were right foot dominant and one of the two males was right foot dominant. Foot dominance was self selected based on the players response to which foot they preferred to kick with for maximal ball velocity. Their age range was 19-22 years. Females had an average body mass of 60.1 kg and an average height of 164.25 cm. Male body mass average was 87.32 kg and height average was 184.15 cm. All subjects declared freedom from physical or orthopaedic injury, which would prevent them from exerting maximal effort in instep kicking. Prior to data collection all subjects warmed-up with flexibility exercises, light running and instep kicking. The use of human subjects was approved by the Institutional Review Board at the School of Medicine of the University of North Carolina at Chapel Hill.

Prior to warm-up, the task to be performed was demonstrated. Following warm-up subjects were randomly assigned to a series of five maximal instep kicks, with dominant and nondominant limbs. Subjects were instructed to take a two-step angled approach of 45-60 degrees to a stationary soccer ball positioned between two force plates, and kick the ball with the instep portion of the foot as hard as possible into netting draped from the ceiling. The dictated approach path has been earlier demonstrated to produce maximum ball velocity in instep kicking (Isokawa and Lees, 1988). Subjects were instructed to plant their support foot on the force plate, which was flush with the floor, and kick with the instep portion of their foot as hard as possible. The force data will not be presented in this manuscript. There was approximately 60 seconds between kicks and two minutes when sides were changed. Following a verbal cue, subjects were instructed to kick as straight as possible without concern of accuracy. A standard size 5 soccer ball was used throughout the testing procedure. Ball pressure was checked periodically to insure standardization during the trials. Each subject wore personal indoor soccer shoes.

Two S-VHS video cameras were used to record subjects' performances at a frame rate of 120 frames/second. The angle between the optical axes of the two video cameras was about 120 degrees. A calibration frame with 24 calibration points that covered a 2 m long 1.5 m wide 2.5 m high space was used to calibrate the space in which subjects performed instep kicking. An external light was used to synchronize the two video cameras. Peak Motus version 4.3 videographic data acquisition system (Peak Performance, Englewood, CO) was used to manually digitize the video records of the calibration frames, and subjects' performances. MotionSoft MS DLT computer program package version 4.0 (MotionSoft, Chapel Hill, NC) with a Direct Linear Transformation algorithm was used to estimate 3-D coordinates of 21 body landmarks and the center of the soccer ball for each trial from SFC to at least three frames after the soccer ball left the kicking foot. The estimated raw 3-D coordinates were filtered through a Butterworth low-pass digital filter at an estimated optimum cutoff frequency of 10 Hz (Yu and Andrews, 1999).

Instantaneous velocities of the soccer ball, the toe of the kicking foot, and ankle and the knee joint of the kicking leg, and instantaneous angular velocity of the knee joint were estimated using MotionSoft MS Kime computer program package version 4.0 (MotionSoft, Chapel Hill, NC). Maximum velocity, and velocity at ball contact of the toe of the kicking foot were identified. The mean velocity and acceleration of the toe of the kicking foot were also estimated between the support foot contact with the ground and ball contact. The kinematic variables chosen for analysis are defined as:

(1) Maximum Toe Velocity (Max T Vel) was the maximum velocity of the distal end of the kicking foot between SFC with the floor and ball contact (BC)

(2) Toe Velocity at Ball Contact (BC Toe Vel) was velocity of the distal end of the kicking foot at the point of BC

(3) Mean Toe Velocity Between SFC and BC (Mean T Vel) was the average velocity of the distal end of the kicking foot between SFC and BC

(4) Mean Toe Acceleration (Mean T Accel) was the average acceleration of the distal end of the kicking foot between SFC and BC

(5) Ankle Velocity at BC was the velocity of the centroid of the lateral malleolus of the kicking foot at BC

(6) Angular Velocity of the Knee at BC was the angular velocity, calculated relative to the thigh segment at BC

The three trials with the greatest ball velocity for dominant and nondominant sides were selected for data analysis.

An analysis of variance was conducted to compare each above defined kinematic variable of kicking between dominant and nondominant limbs and between genders. A 0.05 alpha level was used to indicate statistical significance. All statistical analyses were performed using SAS Software (SAS-Cary, NC). Parametric statistics were used to account for individual effects, the effects due to dominant and nondominant limbs and the effect of gender on the outcomes of interest.

RESULTS

Ball velocity (BV; Table 1), the dependent variable, was significantly different when comparing between sides and genders. There were also statistically significant differences in body mass index (BMI) ($p=0.01$). The mean female BMI was 22.25 and the male mean BMI was 25.75. BMI was calculated as body mass in kg divided by height in meters squared.

Table 1. Ball velocity (BV, m.s^{-1}).

Gender	Dominant BV	Nondominant BV
Male	25.3 ±1.51 *	23.6 ± 1.57*
Female	21.5 ± 2.44	18.9 ±2.05

*p<0.001

Dominant (D) and nondominant (ND) comparisons demonstrated that males had statistically significant ($p<0.05$) greater kinematic values than the females in 3 of the 6 variables on the D side and in 4 of the 6 variables on the ND side (Tables 2 and 3).

Table 2. Means and standard deviations for dominant kinematic variables by gender.

VARIABLES	MALE	FEMALE
Max T Vel (m.s^{-1})	20.4 ±1.3*	18.7 ±2.9
BC Toe Vel (m.s^{-1})	18.9 ±1.6*	16.2 ±2.3
Mean T Vel (m.s^{-1})	13.9 ±1.1	13.5 ±2.1
Mean T Accel (m.s^{-2})	78.3 ±7.6	77.2 ±14.5
Ankle Vel@BC (m.s^{-1})	13.8 ±1.0*	11.9 ±1.1
Ang Vel Kn@BC (rad.s^{-1})	19.4 ±1.9	19.8 ± 4.5

*p<0.05

Table 3. Means and standard deviations for non-dominant kinematic variables by gender.

VARIABLES	MALE	FEMALE
Max T Vel (m.s^{-1})	18.5 ±1.6*	16.2 ± 2.5
BC Toe Vel (m.s^{-1})	17.7 ±1.2*	14.8 ±2.1
Mean T Vel (m.s^{-1})	12.9 ±1.1*	12.2 ±1.8
Mean T Accel (m.s^{-2})	63.3 ±6.9	61.3 ±8.7
Ankle Vel@BC (m.s^{-1})	12.2 ±0.9 *	9.9 ±1.2
Ang Vel Kn@BC (rad.s^{-1})	16.4 ±1.4	16.1 ±4.0

*p<0.05

Angular velocity at the knee at BC was greater among the females than among the males on the D side (19.79 rad.s^{-1} {±4.49}versus 19.42 rad.s^{-1}{±1.87}), but less on the ND side (16.37 rad.s^{-1}{±1.43}versus (16.12 rad.s^{-1}{±4.0}), although the differences were not statistically significant. One elite female's values were similar to those seen in the males. As noted in Figures 1 and 2 when the elite female was compared with the most elite male her toe speed from the beginning to the end of the kick was faster than the male and the angular velocity at the knee was lower at ball contact than the male value.

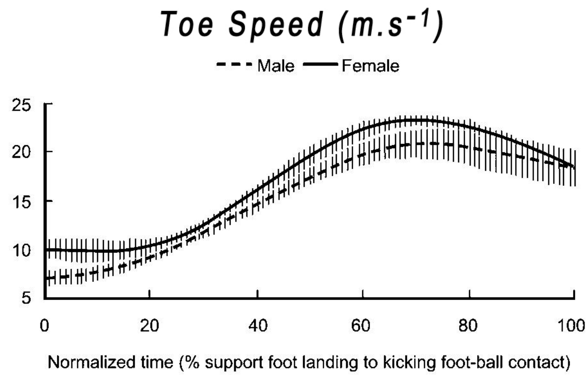

Figure 1. Toe speed comparison between elite male and elite female.

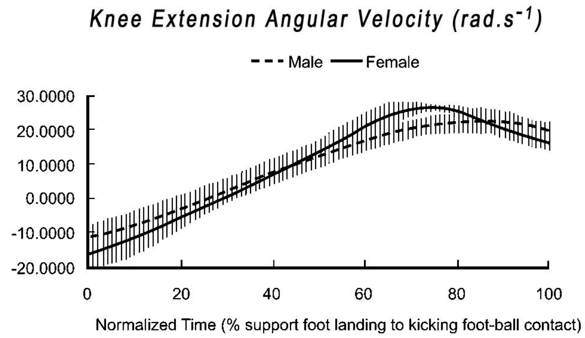

Figure 2. Knee extension angular velocity comparison between elite male and elite female.

DISCUSSION

There have been a number of papers on the mechanics of instep kicking from youth to the elite level (Asami and Nolte, 1983; Barfield, 1993; Barfield, 1995; Barfield, 1997; Narici et al., 1988; Rodano and Tavana, 1993), but all have used male subjects. In addition there have been no investigations involving elite females. Identification of kinematic variable differences may play a critical role in teaching and training of aspiring young female soccer players.

The temporal interactions investigated and the variables chosen for analysis were those previously demonstrated in earlier studies to be important in successful instep kicking (Barfield, 1995; Abo-Abdo, 1981; Dos Anjos and Adrian, 1986). The IK was selected for analysis because, at this time, there are no known studies of this principle skill among elite female soccer players, and the importance of this particular skill in the game of soccer. Dominant and nondominant limbs were examined because of the importance of developing similar bilateral ability, especially in a skill as crucial to success in soccer as instep kicking.

Overall, our apriori hypotheses were supported by the data analysis of our sample. Females generally generated less ball velocity than their male counterparts on dominant and nondominant sides, and the kinematic variables investigated were lower in females compared with the males, however the differences were small. An unanticipated finding was that one of the female subjects generated greater ball velocity on two of her three kicks than the men on the dominant side. With her three values subtracted from the female average the female mean for ball speed for the dominant side dropped to 20.55 m.s^{-1}; the same value as the one elite females lowest velocity kick. With the single female athlete's instep kicking velocity values subtracted from the female mean the differences between the two groups in our sample is even greater. The mean of the three kicks on the dominant side for this one elite woman was 24.15 m.s^{-1}. On the nondominant side the differentials for ball velocity are even more striking. If the one elite female player with the greatest ball speed has her kicking velocity values subtracted from the female mean the variable drops to 18.18 m.s^{-1}, while the mean of the three nondominant kicks for the one elite female is 23.0 m.s^{-1}, similar to the male mean, 23.6 m.s^{-1}.

Maximum toe velocity is significantly greater in males on dominant and nondominant sides (Tables 2 and 3). Although female subjects generally showed lower maximum toe velocities than did the male subjects for dominant and nondominant legs, one female subject showed a mean maximum toe velocity of 23.4 m.s^{-1} with her dominant leg, which is 3 m.s^{-1} faster than the male values on the dominant side. On the nondominant side this one female subject showed a mean value, for this variable, of 20.85 m.s^{-1}, which is over 2 m.s^{-1} faster than the elite male subjects (18.5 m.s^{-1}). These values are similar to an earlier study that examined this variable (Barfield, 1995).

Female subjects' BC toe velocity on dominant and nondominant sides are 86% and 84% respectively of the male value, as seen in Tables 2 and 3, yet are similar to values reported by Barfield, 1995. The lone elite female athlete had a mean value of 20.13 m.s^{-1} for the dominant side and 18.35 m.s^{-1} for the nondominant side. Both mean values were greater than the men, demonstrating that this single female soccer athlete can kick as fast as elite men when kinematic variables other than eventual ball velocity are considered. Deleting this female subject from the data analysis would significantly reduce the mean of the kinematic variables and compound the differences of the kinematic variables between genders.

Differences in magnitude between males and females for mean toe velocity between SFC and BC are not great, especially when compared with some of the other examined variables. Since there are such clear differences in toe velocity at BC and not such differences when the mean value between SFC and BC is examined it may be speculated that males and the single elite female generate speed of this distal segment at the optimal time, that is, at foot/ball contact, whereas the other females in our study do not.

The mean values for toe acceleration for males and females in this investigation are similar in magnitude on dominant and nondominant sides and closely mimic values from an earlier study examining this variable (Barfield, 1993). The single elite female had a mean of 85.04 m.s^{-2} compared with the male values of 78.33 m.s^{-2} on the dominant side and 63.32 m.s^{-2} compared with 63.27 m.s^{-2} on the nondominant side, supporting the hypothesis that elite males generally demonstrate larger kinematic variables than elite women.

Ankle velocity at BC was significantly different on dominant and nondominant sides, and between genders and are similar to the findings from an earlier study (Barfield, 1995). The one elite female kicker had values on dominant and nondominant sides approaching the male values (13.69 m.s^{-1} and 11.29 m.s^{-1} respectively). In a maximal effort activity, like instep kicking, athletes would want this variable to be maximal at BC so that the ball can be propelled with maximal speed. With the one female value taken from the overall female values their mean decreases further for this variable.

Unexpectedly, knee angular velocity at BC was not statistically different between males and females. As the kicking foot approaches contact with the ball, kicking for maximal ball velocity demands optimal angular velocity at the knee. Interestingly, of the seven kinematic variables only dominant knee angular velocity was greater in females than in the males. When the one elite female kicker's values are taken from the calculations on the D side the female knee angular velocity value increases 0.21 rad.s^{-1}, which means females have a mean knee angular velocity of 0.75 rad.s^{-1} faster than men at BC.

Extension torque at the knee prior to BC creates the moment necessary to propel the ball however, the flexion moment (280 N·m) immediately following BC has been shown to be larger than the extensor moment to reduce the injury potential associated with hyperextension. The temporal association of these two events dictates kicking velocity success. Flexion torque initiated too early in the kicking movement slows the limb and kicking foot prior to BC, subsequently decreasing eventual ball velocity. On the other hand, limiting the milliseconds of time available to dissipate stored energy from the kick increases the muscle force required to slow the extending limb and places the kicker at risk for injury because of the large loads placed on the knee joint and soft tissues under tension immediately following the kick (Gainor et al., 1978). Gainor and colleagues have demonstrated that at the termination of knee extension, when kicking with maximal effort, the hamstrings work eccentrically to slow knee extension. This appears to be the case with the males and the one elite female in this study. The one elite female kicker had a mean angular knee velocity on the dominant side of 18.8 $rad.s^{-1}$, 0.98 $rad.s^{-1}$ slower at BC than the mean for the other four women. On the ND side the one elite female had an angular velocity at the knee 1.5 $rad.s^{-1}$ slower than the mean for the other four females and 1.75 $rad.s^{-1}$ slower than the males.

CONCLUSIONS

When differences in the seven kinematic variables examined in instep kicking were analyzed there were significant differences between males and females, although the differences were small. If the dominant limb is established as the "ideal model" in kinematic terms, males demonstrate higher values. The one variable where females demonstrated a greater value was angular velocity at the knee at BC, which may be indicative of a protective mechanism to prevent hyperextension at the knee following a powerful kick by the men and the one elite female. Most females in this study demonstrated greater angular velocity at the knee at BC, which may place them in a more vulnerable position for knee hyperextension. However, the question of how much angular velocity should be slowed to reduce or prevent injury associated with hyperextension at the knee is not a question that was addressed in this investigation.

The fact that men consistently kick harder than women is not newsworthy for many reasons, including the influence of prior training, body size, that contributes to momentum of the body and ultimately the kicking limb through transfer of momentum, and muscle mass. The single female in our study provides an intriguing challenge. Prior to data collection, based on simple observation, one of the female athletes kicked the ball hard and with great power. These empirical observations were confirmed by the kinematic data. The question to be addressed eventually is how can she exhibit such superior kicking ability? Will this be important to women's soccer at the elite level? What will the “trickle down” effect from a teaching/training perspective be for aspiring athletes of both genders?

In the current study men, kick the ball with greater ball velocity than women. They accomplish this with less angular velocity at the knee at BC, but with greater linear velocity of the distal kicking segment. Based on our data elite women generate slower ball velocities with greater angular velocity at the knee, compared with men, and with smaller velocities and accelerations at distal segment.

The position of the foot at ball contact may be an important factor not examined in this study. That is, if the kicking foot of the female player is not firm at ball contact, despite greater angular velocities at the knee, the ball/foot interface will be compromised, and therefore the resultant ball velocity will be less due to attenuation of force between the foot and the contact surface on the ball (Tsaousidis and Zatsiorsky, 1996). There is also evidence that an efficacious strength training program which encompasses concentric and eccentric exercises improves kicking distance and power (DeProft et al., 1988a; 1988b), yet game and training conditions also create a stimulus which generates sufficient bilateral exercise to prevent muscle imbalance and asymmetry, an important aspect in soccer (Bollens et al., 1987; Cabri et al., 1988; Mognoni et al., 1994). The fact that we did not measure muscle torque may or may not have been an important variable based on prior research in this area. We speculate that since measurements were taken during the traditional spring training period both groups were actively involved in weekly training periods with the without the ball, which would mean a similar training stimulus for strength development.

The findings from the current study include:

1) Females have the ability to instep kick on dominant and nondominant sides with similar kinematic characteristics as men,

2) Six of the seven kinematic variables examined on dominant and nondominant sides were greater among males than females, yet angular velocity at ball contact, an important contributor to ball speed was slower in the male kickers compared with the females. This may be indicative of male ability to generate greater momentum of the distal segment prior to BC. This provides time, prior to BC,

for the hamstrings to initiate a reduction in knee angular velocity as BC approaches to reduce injury potential through hyperextension,

3) Slower angular velocity at the knee for the dominant side in males may be indicative of a protective mechanism to slow the limb prior to BC to reduce potential injury.

Based on our results, elite female players do not possess the same instep kicking power as males, however there are exceptions. Instep kicking, because of the importance of this particular skill to soccer, will continue to be a topic requiring discussion and research in the field of biomechanics because of a number of unresolved issues including: definitive fractionization of moments and forces at the hip and knee, the relative contributions each makes to kicking, the eccentric role of the hamstrings as a protective mechanism and differ-ences that exist between the genders. Soccer participa-tion continues to grow which will fuel active, ongoing research to improve training and teaching, prevent injury, and to assist with rehabilitation techniques.

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REFERENCES

Abo-Abdo, H.E. (1981) *Kinematic and kinetic analysis of the soccer instepkick*. Doctoral dissertation, Indiana University, Bloomington, IN.

Asai, T., Kobayashi, K. and Oshima, Y. (1980) Biomechanical analysis of instep kick in soccer. *Proceedings of Japanese Physical Education*, 139.

Asami, T. and Nolte, V. (1983) Analysis of powerful ball kicking. In *Biomechanics VIII-B*. Eds: Matsui, H. and Kobayashi, K. Champaign, Il: Human Kinetics, 695-700.

Barfield, W.R. (1993) *Effects of selected biomechanical variables on a coordinated human movement:instep kicking with dominant and nondominant feet.* Doc-toral dissertation, Auburn University, Auburn, AL.

Barfield, W.R. (1995) Effects of selected kinematic and kinetic variables on instep kicking with dominant and nondominant limbs. *Journal of Human Movement Studies* **29,** 251-272.

Barfield, W.R. (1997) Biomechanics of kicking. In *Textbook of Sports Medicine*. Eds: Garrett, W.E. and Kirkendall, D.T. Baltimore: Williams & Wilkins, 86-94.

Ben-Sira, D. (1980) A comparison of the mechanical characteristics of the instep kick between skilled soccer players and novices. Doctoral dissertation, University of Minnesota, Duluth, MN.

Bloomfield, J., Elliott, B. and Davies, C. (1979) Development of the soccer kick:a cinematographical analysis. *Journal of Human Movement Studies* **3,** 152-159.

Bollens, E.C., DeProft, E. and Clarys, J.P. (1987) The accuracy and muscle monitoring in soccer kicking. In *Biomechanics X-A*. Ed: Jonsson, B. Champaign, IL:Human Kinetics Publishers, 283-288.

Butterfield, S.A. and Loovis, E.M. (1994) Influence of age, sex, balance, and sport participation on developemnt of kicking by children in grades K-8. *Perceptual and Motor Skills* **79,** 691-697.

Cabri, J., DeProft, E., Dufour, W. and Clarys, J.P. (1988) The relation between muscular strength an kick performance. In *Science and Football*. Eds: Reilly, T., Lees, A., Davids, K., and Murphy, W.J. New York: E & F.N. Spon, 186-193.

Chyzowych, W. (1979) *The Official Soccer Book of the United States Soccer Federation*. Rand McNally, New York.

DeProft, E., Cabri, J., Dufour, W. and Clarys, J.P. (1988a) Strength training and kick performance in soccer players. In *Science and Football*. Eds: Reilly, T., Lees, A., Davids, K., and Murphy, W.J. New York: E & F.N. Spon, 108-113.

DeProft, E., Clarys, J.P., Bollens, E., Cabri, J. and Dufour, W. (1988b) Muscle activity in the soccer kick. In *Science and Football*. Eds: Reilly, T., Lees, A., Davids, K., and Murphy, W.J. New York: E & F.N. Spon, 434-440.

Dos Anjos, L.A. and Adrian, M.J. (1986) Ground reaction forces during soccer kicks performed by skilled and unskilled subjects. *Revista Brasileira de Cienias do Esporto (abstract)*. Sao Paulo, Brazil.

Dunn, E.G. and Putnam, C.A. (1988) The influence of lower leg motion on thigh deceleration in kicking. In *Biomechanics XI-B*. Eds: deGroot, G., Hollander, P., Huijing, P.A., and van Ingen Schenau, G.J. Amsterdam: Free University Press, 787-790.

Elliott, B.C., Bloomfield, J. and Davies, C.M. (1980) Development of the punt kick:a cinematographical analysis. *Journal of Human Movement Studies* **6,** 142-150.

Gainor, B.J., Piotrowski, G., Puhl, J.J. and Allen, W.C. (1978) The kick:biomechanics and collision injury. *American Journal of Sports Medicine* **6,** 185-193.

Hay, J.G. (1996) *The biomechanics of sports techniques-fourth edition*. Prentice Hall, Englewood Cliffs, NJ.

Huang, T.C., Roberts, E.M. and Youm, Y. (1982) Biomechanics of kicking. In *Human Body Dynamics:Impact, Occupational, and Athletic Aspects*. Ed: Ghista, D.J. New York: Clarendon Press & Oxford University Press. 409-443.

Isokawa, M. and Lees, A. (1988) A biomechanical analysis of the instep kick motion in soccer. In *Science and*

Football . Eds: Reilly, T., Lees, A., Davids, K., and Murphy, W.J. New York: E & F.N. Spon, 449-455.

Kaufmann, D.A., Stanton, D.E. and Updyke, W.F. (1975) Kinematical analysis of conventional-style and soccer style place kicking in football. *Medicine & Science in Sports & Exercise* **7,**77-78 (abstract).

Lindbeck, L. (1983) Impulse and moment of impulse in the leg joints by impact from kicking. *Journal of Biomechanical Engineering* **105,** 108-111.

Luhtanen, P. (1988) Kinematics and kinetics of maximal instep kicking in junior soccer players. In *Science and Football*. Eds: Reilly, T., Lees, A., Davids, K., and Murphy, W.J. New York: E & F.N. Spon, 441-448.

Mognoni, P., Narici, M.V., Sirtori, M.D. and Lorenzelli, F. (1994) Isokinetic torques and kicking maximal ball velocity in young soccer players. *Journal of Sports Medicine and Physical Fitness* **34,** 357-361.

Narici, M.V., Sirtori, M.D.and Mognoni, P. (1988) Maximal ball velocity and peak torques of hip flexor and knee extensor muscles. In *Science and Football*. Eds: Reilly, T., Lees, A., Davids, K., and Murphy, W.J. New York: E & F.N. Spon, 429-433.

Nishijima, T., Tasaki, E., Noda, Y. and Tanaka, K. (1996) Development of principal motor movements controlling ball kicking performance. *ACSM National Meeting Proceedings* (abstract).

Olson, J.R. and Hunter, G.R. (1985) Anatomic and biomechanical analyses of the soccer style free kick. *National Strength and Conditioning Association Journal* **7,** 50-53.

Phillips, S.J. (1985) Invariance of elite kicking performance. In *Biomechanics IX-B*. Eds: Winter, D.A., Norman, R.W., Wells, R.P., Hayes, K.C., and Patla, A.E. Champaign, IL: Human Kinetics Publishers, 539-542.

Plagenhoff, S. (1971) *Patterns of human motion: a cinematographic analysis*. Prentice-Hall, Englewood Cliffs, N.J.

Putnam, C.A. (1991) A segment interaction analysis of proximal-to-distal sequential segment motion patterns. *Medicine & Science in Sports & Exercise* **23,** 130-144.

Roberts, E.M. and Metcalfe, A. (1968) Mechanical analysis of kicking. In *Biomechanics I* Eds: Wartenweiler, J., Jokl, E., and Hebbelinck, M. Baltimore:University Park Press. 315-319.

Robertson, D.G.E. and Mosher, R.E. (1985) Work and power of the leg muscles in soccer kicking. In *Biomechanics IX-B*. Eds: Winter, D.A., Norman, R.W., Wells, R.P., Hayes, K.C., and Patla, A.E. Champaign, IL: Human Kinetics Publishers, 533-538.

Rodano, R. and Tavana, R. (1993) Three-dimensional analysis of instep kick in professional soccer players. In: *Science and Football II* . Eds: Reilly, T., Clarys, J., and Stibbe, A. New York: E. & F.N. Spon, 357-361.

Tsaousidis, N. and Zatsiorsky, V. (1996) Two types of ball-effector interaction and their relative contribution to soccer kicking. *Human Movement Science* **15,** 861-876.

Yu, B. and Andrews, J.G. (1999) The relationship between free limb motions and performance in the triple jump. *Journal of Applied Biomechanics* **14,** 223-237.

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