REGRESSION EQUATIONS FOR ESTIMATING THE QUALITY OF MAXIMAL INSTEP KICK BY MALES AND FEMALES IN SOCCER

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Original scientific paper
UDC: 577.35:796.332-053.6

Abstract:

Biomechanics research of soccer skills has greatly lagged behind the sport's popularity compared to many other sports. Even for basic skills, such as the maximal instep kick, relatively few quantitative studies exist. Further, most of these fail to provide practical means to judge kick quality. The current study proposes to address this deficiency by establishing user-friendly regression equations that apply to both novice and advanced players. These allow an easy way for coaches/teachers to evaluate kick quality. The method consisted of 3D data collection (VICON system with nine high-speed cameras, 120 Hz), full-body biomechanical modeling and correlation and regression analyses of ball release speed with flexion/extension of shoulder, trunk, hip, knee and rotation of trunk as well as last stride length and body height. Twenty-four male and twenty-six female college students, equally divided into novice and advanced cohorts, participated. Results showed many of the correlations to be reliable predictors of a kick's effectiveness. However, they are not practical since extensive use of technology and time-consuming data processing is needed. Further analyses showed multi-regressions using last stride length and body height as independent parameters to have equally reliable evaluation potential. The study concludes that, since the last two independent parameters are easy to measure, these regression equations provide an eminently practical means to evaluate the maximal instep soccer kick.

Key words: *3D motion capture, full-body modeling, last stride length, body height*

Introduction

Soccer is played and watched by over 270 million participants worldwide (FIFA, 2007). Surprisingly, quantitative research, for even basic skills, is relatively scarce (Shan, 2009). Perhaps research is hindered by: 1) limitations of laboratory/in-game data collection, and 2) confounding issues such as skill diversity, exacerbated by the fact that soccer is a team activity. Game situations make it difficult to collect unconstrained data, necessitating laboratory-based collection as a proxy for contextual research. The current study examines the maximal instep kick, mimicking game-like conditions as much as feasible.

Objectively, kick "quality" refers to both accuracy and power. Accuracy measures the precision when driving the kicking foot toward the target. Power is related to kicking-foot momentum. The highest quality of kick is achieved when the ball is struck accurately with full power. However, accuracy and power are non-autonomous variables. Typically they interact contrarily (Magill, 2001). Especially for novice learners, power and accuracy can dramatically work against each other. Hence, because an understanding of optimized kicking characteristics will help coaches better develop goal-oriented training regimes, kicking has been the subject of most biomechanical soccer studies (Kellis & Katis, 2007; Lees, 2003).

The literature reveals several kicking studies using 2D motion analysis, at sampling rates ranging from 64 to 200 Hz (Asami & Nolte, 1983; Lees & Nolan, 1998; Opavsky, 1988; Luhtanen, 1994; Zernicke & Roberts, 1978). Typically they analyzed: ball speed, joint angles/changes, and angular velocities. Such 2D studies cannot describe full-body movements without losing important characteristics. Other studies use 3D analyses, but most only engage in partial body modeling (Apriantono, Nunome, Ikegami, & Sano, 2006; Levanon & Dapena, 1998; Nunome, Ikegami, Kozaki, Apriantono, & Sano, 2006; Rodano & Tavana, 1993). Quantitative full-body 3D analyses are rare (Shan & Westerhoff, 2005).

Empirical evidence suggests that maximal instep kicking is strongly influenced by the upper body movement, including trunk twisting (Figure 1). Clearly, 2D or partial 3D analyses cannot provide a holistic view of the skill. Full-body 3D analysis is necessary, especially for identifying the function of the upper-body movement. The initial study of Shan and Westerhoff (2005) showed that key characteristics of a maximal instep kick could be summarized as the formation of a tension arc and the fast release of that arc (Figure 2). Tension arc formation involves the kick side (KS) hip over-extension, knee flexion, trunk twist towards the non-kick side (NKS), and the NKS shoulder extension and abduction (Figure 2, left). The release consists of a quasi whip-like control sequence of the kicking leg, upper trunk flexion and twist towards KS, and the NKS shoulder flexion and adduction (Figure 2, right). Through statistical analyses, the study found that the distance between the NKS shoulder and the KS hip relates to kick quality.

Although possessing scientific merit, results of previous studies, both 2D and 3D, have limited practical use. Players and coaches typically have no means to collect and interpret such data under typical training conditions. In order to bridge the gap with practical application, some research studies have tried to develop user-friendly evaluation methods. These focused on simplifying evaluation by measuring one or two parameters that conveyed the kick quality/power. Examples are:

Figure 1. Exemplars of maximal instep kicking – a skill obviously involves leg swing, trunk rotation/twist and arms' movement.

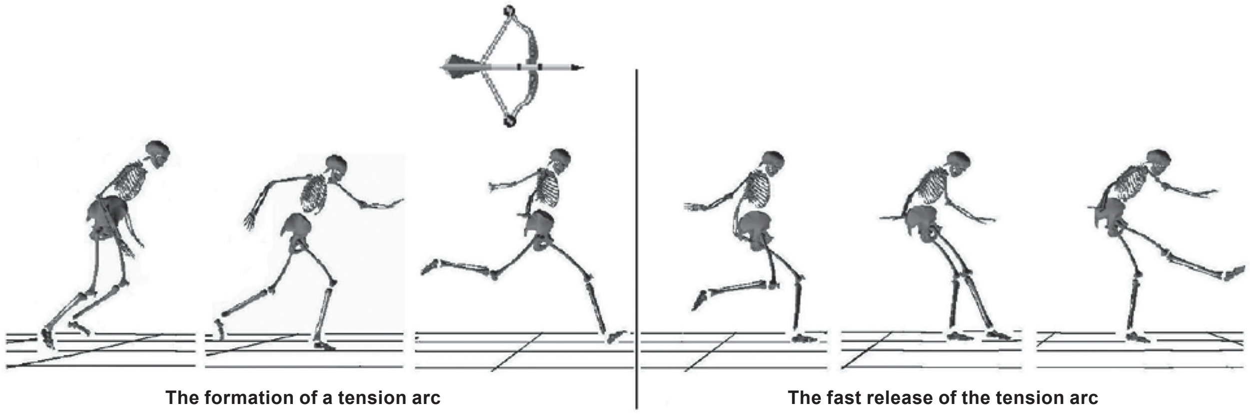

Figure 2. Maximal instep kick in soccer – a typical full-body and multi-joint coordination consisting of the formation of a tension arc and its release.

1) $V_{ball} = 1.23 \times V_{foot} + 2.72$
where V = velocity of the ball and foot, respectively (Zernicke & Roberts, 1978).
2) $V_{ball} = \dfrac{V_{foot} \times M \times (1 + e)}{M + m}$
where V = velocity of the ball and foot, respectively, M = effective striking mass of the leg; m = mass of the ball; and e = coefficient of restitution (Lees, 2003; Bull-Andersen, Dorge, & Thomsen, 1999).
3) The changing range of distance between the NKS shoulder and the KS hip during kick (Shan & Westerhoff, 2005).

However, even these simplified models are not sufficiently "practical" since they use human resource intensive motion analysis technology.

A recent review (Lees, Asai, Andersen, Nunome, & Sterzing, 2010) reveals that the hip movement/last stride length (LSL) could be linked to the tension arc, i.e. as an indicator of the kick quality. The related studies which have tried to draw relationships between the hip movement and kick quality include: kinematic analysis of the range of motion (ROM) for hip–shoulder separation during the kick (Lees & Nolan 2002), 3D full-body kinematic studies of the kick (Shan & Westerhoff, 2005; Shan, 2009) and 3D kinetic analysis of the kicking leg (Kawamoto, Miyagi, Ohashi, & Fukashiro, 2007). The results of the first three studies imply that the hip movement may be considered to represent the tension arc as a quality indicator for the performance (Lees, et al., 2010). The last one has shown that the more hip ROMs are, the greater the hip joint moments are created (Kawamoto, et al, 2007). Collectively, these studies suggest that hip ROM could be an alternative variable of tension arc for quantification of kick quality in practice. Since hip ROM could be easily "translated" to LSL, this approach could have a great potential to become a user-friendly evaluation method. Therefore, this study aims to investigate the specific relationship(s) in more detail in order to fulfill the user-friendly method with reliability comparable to the 3D movement analysis for the quality evaluation of maximal instep kick.

Methods

The study utilizes the well-accepted fundamental premise from literature: the highest quality of kick is achieved when the ball is struck accurately with full power. Typically, training initially concentrates on accuracy and afterward aims to enhance power. Therefore, the development of kick skill is more closely related to power development, which can be correlated to the length of the ultimate stride before the ball is struck. Mathematically, LSL during kicking is related to ROMs of legs and their lengths, and anthropometrically, leg length is proportional to body height (BH) (Shan & Bohn, 2003). As such, for a given LSL, the ROMs of legs during kicking should be inversely proportional to BH, i.e. for the same LSL, different BH athletes should show different qualities of the kicks. Summarized from the current literature theories/results (namely: the tension-arc theory, the obvious linkage between hip movement and the tension arc, as well as the anthropometrical results), one can conclude that the power generation of a kick is influenced by both LSL and BH. To test the correlation of LSL and BH to kick quality, this study explored V_{ball}, parameters related to the tension arc, LSL, and BH for both male and female subjects.

Twenty-four male and twenty-six female subjects participated (95% statistical confidence level, calculated by power analysis). Gender groups consisted of equal numbers of novice and advanced players. All subjects were college students with an average age of 21.7 years (±2.2). Average body heights and masses were 1.75 m±0.05 and 72.4 kg ±2.7 (novice males), 1.76 m±0.04 and 72.6 kg±2.3 (skilled males), 1.65 m±0.03 and 66.3 kg±1.9 (novice females), 1.68 m±0.04 and 67.1 kg±2.0 (skilled females). Novices were undergraduate kinesiology students without significant soccer experience. Skilled players were athletes on the college soccer teams with an average of twelve years of soccer experience. The subjects were volunteers and the study was approved by the Human Subjects Research Committee of the University of Lethbridge. The subjects performed from five to nine warm-up kicks in order to familiarize themselves with the test environment. After the warm-up, the subjects executed three accurately targeted kicks using their dominant foot. Each subject decided on his/her own pace between warm-up and tests, so that the optimal individual control state would be measured. Ground stiffness mimicked grass, using a 2-cm--thick wrestling mat. The subjects aimed at a 5×2m² vertical mat. This mat virtually eliminated rebound, removing any apprehension of ricochets and letting subjects to strike the ball as hard as possible. During each kick, synchronized 3D and video data were acquired. Video was used to provide a traditional method of skill analysis familiar to practitioners. No restrictions were placed on the subjects before or during trials in an effort to preserve subjects' normal motor control style.

A nine-camera VICON motion capture system (Oxford Metrics Ltd., Oxford, England) was used to obtain full-body kinematics, tracking 45 12-mm reflective markers at 120 frames/second. VICON software triangulated positions of each marker and rendered them in 3D computer space. Markers defined a 15-segment body model with 42 body markers and the three ball markers (Figure 3a). Markers were placed as follows: 1) head — one each on the left and right temples and two on the posterior portion of the parietal bone; all four markers were located in the same transverse/axial plane; 2) trunk — one each on the sternal end of the clavicle, xiphoid process of the sternum, C7 and T10 vertebrae, each scapula, left and right anterior and posterior superior iliac spine; 3) upper extremities — one each on the right and left acromion, lateral side of upper arm, lateral epicondyle, lateral side of forearm, styloid processes of radius and ulna, and distal end of 3rd metacarpal bones; and 4) lower extremities — one each on the left and right lateral sides of thigh and shank, lateral tibial condyle, lateral malleolus, distal end of 5th metatarsal, calcaneus and 1st distal phalanx. Calibration residuals were determined in accordance with the manufacturer's guidelines and yielded positional data accurate to <1.5 mm. The three ball markers provided kinematic data for V_{ball}. A standard Fédération Internationale de Football Association (FIFA) ball was used. Ball inflation was controlled for each subject (90–92 kpa).

Raw kinematic data was processed using a five-point (1-3-4-3-1 function) smoothing filter. Resultant data was used to build a 15-segment biomechanical model of the body (Figure 3b): head, two-segment trunk, upper arms, lower arms, hands, thighs, shanks and feet. Inertial characteristics of the model segments were estimated using anthropometric regressions found through statistical studies (Shan & Bohn, 2003). For model calculation, references of Nordin and Frankel (2001) were used to determine joint flexion/extension around transverse axis (medial-lateral direction), abduction/adduction around the sagittal axis (antero-posterio direction) and rotation/twist around the longitudinal axis.

Statistical analyses were focused on parameters related to the formation and release of the tension arc and the correlation of these parameters plus LSL and BH with V_{ball}. In accord with Shan and Westerhoff (2005), the following tension-arc parameters were measured: flexion/extension ROMs of the trunk, NKS shoulder, KS hip and knee, and trunk rotation ROM. LSL was defined as the distance between the KS toe marker at the point of take-off from the ground and the NKS heel marker. The LSL is defined in this way because both of these can leave prints on the soccer field, which are easily measured by practitioners. Data were analyzed using SPSS® (SPSS Inc, Chicago, IL, USA). Results were presented using basic descriptive statistics and, where appropriate, *t*-tests were used to report statistical significance ($p<.05$). Regression analyses between V_{ball} and tension-arc

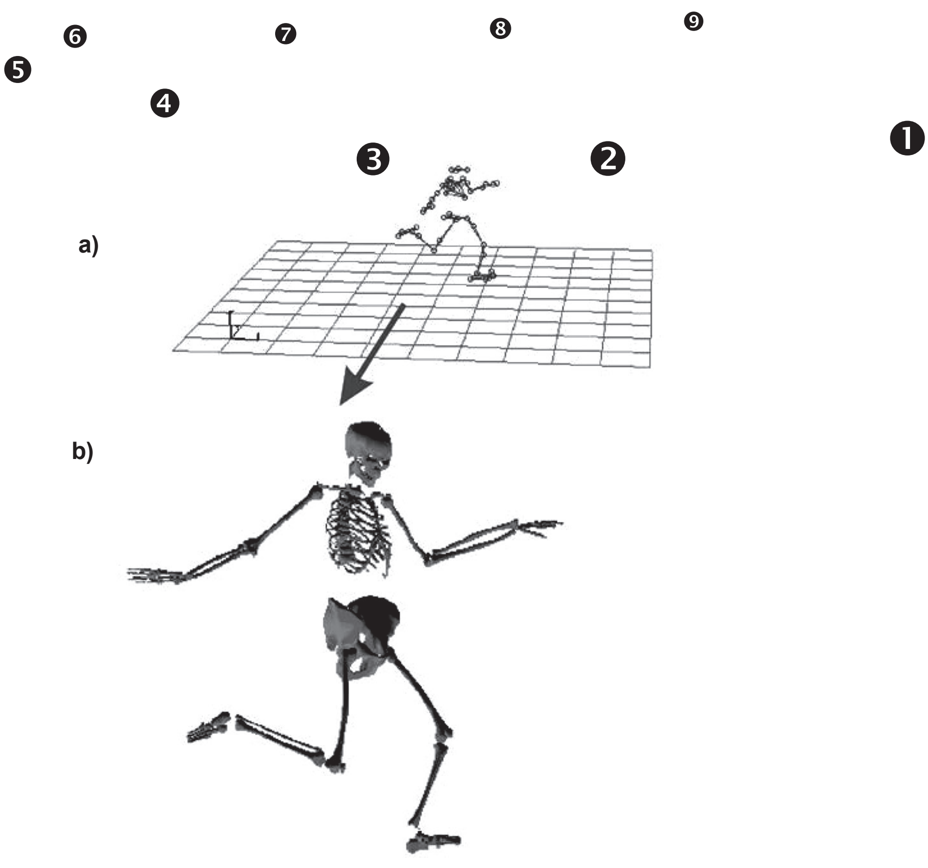

Figure 3. Maximal instep soccer kick – the set-up of 3D data collection, a sample of 3D motion capture and the 15-segment full-body model derived from 3D raw data. Each tiny circle in Figure 3a represents a marker captured. The 3D raw data contains only coordinate information. Through biomechanical modeling, the anatomical positions and markers were linked together to reconstruct a skeleton.

parameters (serve as five independent variables) plus LSL and BH were conducted. Reliability tests (also known as consistency tests – the degree to which a measurement will give similar results for the same individuals at different times), provided by the SPSS software, were performed in order to provide a practical method for predicting kick quality.

Results

Three-dimensional motion analysis revealed distinguishable differences between cohorts of novices and skilled players in ROM of flexion/extension of the shoulder and hip, trunk rotation and LSL. For both genders, skilled cohorts had significantly higher values compared to novice ones ($p<.01$, Table 1). Trunk rotation (female) and knee flexion/extension (males) were also significantly higher in skilled than novice groups ($p<.01$). No significant differences were found for trunk rotation (males) or knee flexion/extension (females) ($p>.05$). V_{ball} was significantly higher for skilled cohorts, both male and female ($p<.01$). BH did not directly affect kick quality ($p>.05$).

Reliability tests using V_{ball}, tension-arc parameters and LSL determined that V_{ball}, LSL, and flexion/extension of shoulder and hip could be used for both genders as a predictor of kick quality, with reliability coefficients (r) ranging between .755 and .986 (Table 2). Male knee flexion/extension and female trunk rotation were also reliable, with coefficients of .513 and .967, respectively. The only two unreliable test parameters were male trunk rotation and female knee flexion/extension, with $r<.331$.

Whereas Table 1 and 2 provide information just on the central tendency and reliability of parameters related to kick quality, the results of correlation and regression analyses can help find practical way(s) to evaluate kick quality. Generally speaking, both novice groups showed low to poor correlations (coefficients $|c|<.456$) between tension-arc parameters and V_{ball} except for the NKS shoulder flexion/extension (male) (Table 3). Correlations between LSL and V_{ball} were high for both genders (c=.692 and .670). These coefficients increased further when multiple correlations using LSL and BH were applied (c=.754 and .728, respectively).

For the skilled players, high correlations existed between V_{ball} and: 1) LSL for both genders, 2) flexion/extension of shoulder, hip and knee for both genders, and 3) female trunk rotation; correlation coefficients ranged from c=.617 to .894. Poor correlation ($|c|=.392$) was found between V_{ball} and male trunk flexion/extension.

Collectively for all males (novice and advanced), correlations were comparable to those for the advanced males only. Collectively for females, correlations were comparable to those for the advanced females except for knee flexion/extension (c=.024). On collective basis, correlation between V_{ball} and LSL increased notably for both genders, from .861 to .931 for males and .824 to .887 for fe-

Table 1. Results of t-test between novice and advanced players during the performance of the maximal instep kick

Group		Quality of tension arc					Length of LSL (m)	Body height (m)	V_{ball} (m/s)
		Flexion/Extension (◦)				Trunk rotation (◦)			
		Shoulder (NKS)	Hip (KS)	Knee (KS)	Trunk				
Male	novice	53.3±7.9	76.7±7.2	85.0±7.9	8.1±1.7	8.4±1.3	1.06±0.11	1.75±0.05	17.2±2.9
	advan.	161.4±15.9	129.2±11.4	110.9±8.3	6.6±1.5	22.5±4.7	1.38±0.07	1.77±0.04	24.5±3.3
	p-value	<.01	<.01	<.01	>.05	<.01	<.01	>.05	<.01
Female	novice	45.6±9.2	69.1±6.3	122.0±14.5	8.7±2.7	9.6±2.5	0.99±0.09	1.67±0.04	13.2±2.3
	advan.	116.7±11.3	91.2±7.8	117.5±8.9	45.6±7.3	25.6±4.8	1.22±0.06	1.68±0.05	19.8±2.8
	p-value	<.01	<.01	>.05	<.01	<.01	<.01	>.05	<.01

Legend: advan: advanced, NKS: non-kick-side, KS: kick-side, LSL: last stride length, V_{ball}: ball release speed.

Table 2. Reliability of the selected parameters

Group	Quality of tension arc					LSL	V_{ball}
	Flexion/Extension				Trunk Rotation		
	Shoulder (NKS)	Hip (KS)	Knee (KS)	Trunk			
Male	.986	.857	.513	.331	.854	.938	.876
Female	.961	.755	.179	.967	.879	.807	.784

Legend: advan: advanced, NKS: non-kick-side, KS: kick-side, LSL: last stride length, V_{ball}: ball release speed.

Table 3. Correlation coefficients of ball release speed with the selected parameters

Group	Single regression							Multiple regression
	Quality of tension arc					LSL	BH	LSL & BH
	Flexion/Extension				Trunk rotation			
	Shoulder (NKS)	Hip (KS)	Knee (KS)	Trunk				
Male (advance)	.894	.891	.834	-.142	.759	.861	.241	.913
Male (novice)	.871	-.456	-.063	-.030	-.016	.692	.192	.754
Male	.873	.873	.873	-.392	.834	.931	.291	.951
Female (advance)	.882	.876	.771	.617	.739	.824	.164	.911
Female˝(novice)	.453	.026	.013	.038	.036	.670	.153	.728
Female	.839	.851	.024	.719	.860	.887	.176	.953

Legend: advan: advanced, NKS: non-kick-side, KS: kick-side, LSL: last stride length, V_{ball}: ball release speed.

males, as did the coefficients for multiple correlations using LSL and BH (Table 3). Considering all results, the highest correlation coefficients for both genders were found from the combined data of novice and advanced players.

Although poor correlation existed between V_{ball} and BH for both genders, previous studies show leg length to be proportional to BH regardless of gender and race (Shan & Bohn, 2003). Since stride length is determined by leg length and flexibility, BH should be a compounding parameter that indirectly influences ball release speed. From this and correlation analysis results, multiple regression equations were established for both genders (equations [1] and [2] for males and females, respectively). The equations predicted V_{ball} using LSL and BH as independent parameters.

For males: $V_{ball} = 35.175 + 29.514 \times LSL - 27.982 \times BH$ [1]
For females: $V_{ball} = 35.155 + 28.713 \times LSL - 28.875 \times BH$ [2]
Note: both LSL and BH are measured in meters.

Correlations between measured V_{ball} and predicted V_{ball} revealed the efficacy of multi-regressions based on LSL and BH: coefficients reached values as high as .951 and .953 for males and females, respectively (Table 3, last column).

Discussion and conclusions

V_{ball} is used to evaluate kick quality and is highly related to tension-arc formation and release (Shan & Westerhoff, 2005). However, both of these require 3D measurements and time-intensive data crunching. So, they are not “user-friendly”. Hence, the current study examines the efficacy of an easy and practical approach to evaluation of kick quality.

The study confirmed distinguishable differences between novices and skilled players. First, significant V_{ball} differences between novice and advanced players for both genders demonstrated that V_{ball} was indeed an effective parameter to evaluate kick quality. Second, results confirmed that most tension-arc parameters also provided valid means of evaluation. Third, results showed LSL to be a legitimate evaluation parameter since it showed significantly higher values for experienced players than novices for both genders.

One aim of this study was to examine the reliability of kinematic parameters related to kick quality. Considering the reliable increasing tendency of correlations between V_{ball} and tension-arc parameters or LSL from novice to advanced stage, reliable estimations for kick quality do exist, although there were two exceptions – female knee flexion/extension and male trunk rotation. Based on previous studies, the large variation found in these two parameters are likely caused by gender and training. After a powerful kick, females counteract residual leg momentum with upper body flexion and rotation (Shan, Daniels, Wang, Wutzke, & Lemire, 2005) while males dissipate moment by naturally following through with a jump (Shan, 2009). Consequently, males lack consistent trunk rotation. As for the exception of female knee flexion/extension, experienced females use both flexion/extension of the hip and knee to initiate the kicking movement (Anderson & Sidaway, 1994; Shan, 2009), while novice females relied mainly on the motion at the knee to create the power necessary for the kick (Shan, 2009; Shan, et al., 2005). Thus novice and advanced females have comparable movements at the knee. Because these exceptions are isolated ones, the group concept of using tension arc and LSL for quality evaluation is still valid.

Correlation and regression analyses using V_{ball}, LSL and selected tension-arc parameters further illuminate which of them could best evaluate kick quality. Although tension-arc parameters are very useful for coaches and athletes to both understand control of the skill and guide the training, soccer coaches and players find that they are hard to measure, whereas LSL is not. It is a simple distance measurement of footprints left on the soccer field. As results indicated, LSL possessed high reliability and correlation to kick power. It could be an ideal parameter for practitioners to evaluate the effects of training. Further, the data suggested that adding BH into the correlation and regression analysis improves the reliability of the evaluation. Since BH is also easy-to-measure, using multiple regressions is as practical as using a single one. As such, multi-regression based on LSL and BH, in place of single-regression on LSL only, provides practitioners an even better method.

Finally, regression equations can predict the joint-effect of power and accuracy for a player's kick. Relative stride length (stride length in relation to the body height) is proven a good indicator for evaluating this joint effect, i.e. the evaluation using the regressions is only valid when the kick hits the ball accurately. Normally, one can feel if one hits the ball accurately. A coach can also judge the accuracy by observing the ball release angle (inaccurate when too low or too high) and/or ball release direction (inaccurate when diverse from kicking direction). Learners very often apply a large relative stride length for increasing kick power, but accuracy decreases during training. *One should keep in mind that evaluations using the regressions supplied in this study only work with accurate kicks*. Therefore, evaluation using these equations presupposes accuracy and then evaluates power.

A potential limitation of applying multi-regressions is its unknown applicability to groups not represented within this study. The subjects tested here were all college students; thus the equations may not predict well for children or elite players. For delimitation of the established equations or creation of new equations for those groups, further studies are needed. Additionally, it should be noted that factors limiting the players' ability to perform a kick (e.g. environmental constraints in a game) were not considered in the current study. Therefore, the equations can only be applied when a maximal instep kick is performed.

In conclusion, the current study confirms that LSL and BH (i.e. relative stride length) highly correlate to tension-arc quality and ball-release speed, and the correlations differ based on gender. The multi-regressions of the study provide practitioners an easy method for the evaluation of the maximal instep kick; one equally reliable to 3D motion-capture method. Thus the study supplies a potentially practical tool to evaluate kicking development during training.

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Submitted: April 21, 2011
Accepted: December 12, 2012

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Acknowledgement

This work was supported by the National Science and Engineering Research Council of Canada (NSERC) and Westgrid (Canada).

REGRESIJSKE JEDNADŽBE ZA PROCJENU KVALITETE IZVEDBE MAKSIMALNOG OSNOVNOG NOGOMETNOG UDARCA U MUŠKARACA I ŽENA

U usporedbi s drugim sportovima, biomehanička istraživanja vještina u nogometu uvelike zaostaju za razinom popularnosti toga sporta u svijetu. Čak i za osnovna nogometna znanja, kao što je osnovni nogometni udarac izveden punom snagom, postoji relativno malo kvantitativnih istraživanja. Nadalje, većina tih istraživanja nije ponudila praktična rješenja za ocjenjivanje kvalitete udarca. Ovo istraživanje usmjereno je na rješavanje tih nedostataka postavljanjem praktičnih regresijskih jednadžba koje se mogu primijeniti za procjenu kvalitete izvođenja udarca početnika i naprednih nogometaša. Korištenje regresijskih jednadžba omogućit će nogometnim trenerima i profesorima tjelesne i zdravstvene kulture jednostavnu procjenu kvalitete udarca. Metoda se sastoji od prikupljanja 3D podataka (VICON sustav sa 9 visoko-frekventnih kamera, 120 Hz), biomehaničkog modeliranja cijelog tijela te korelacijskih i regresijskih analiza povezanosti početne brzine lopte nakon udarca s pregibanjem/opružanjem ramena, trupa, kuka, koljena i s rotacijom trupa te duljinom posljednjega koraka i visinom tijela. U istraživanju su sudjelovala 24 studenta i 26 studentica koji su raspoređeni u jednake početničke i napredne grupe. Rezultati su pokazali da je velik broj korelacija bio pouzdan prediktor učinkovitosti udarca. Ipak, tolike korelacije nisu praktične budući da zahtijevaju uporabu mnogih uređaja i dugotrajnu obradu podataka. Daljnje analize pokazale su da višestruke regresije, koje se temelje na duljini posljednjega koraka i visini tijela kao nezavisnim varijablama, imaju jednak potencijal pouzdanosti za ocjenjivanja kvalitete izvođenja udarca. Budući da je duljinu posljednjega koraka i visinu tijela lako mjeriti, zaključak je ovog istraživanja da su predložene regresijske jednadžbe vrijedno praktično sredstvo za vrednovanje kvalitete maksimalnog osnovnog nogometnog udarca.

Ključne riječi: *3D snimanje gibanja, modeliranje cijelog tijela, duljina posljednjega koraka, visina tijela*