©Journal of Sports Science and Medicine (2010) **9**, 382-387
http://www.jssm.org

Research article

Consistency in acceleration patterns of football players with different skill levels

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Abstract
The aims of the present study were to compare the consistency in the lower limb acceleration patterns during inside and instep kicks performed by players with different skill levels, and to investigate the correlation between subjective rating scores for skill level relative to their kicking performance and knee acceleration repeatability. Thirteen club-level male soccer players of ages between 15-16 years participated in this study. Skill levels of individual players were quantified previously by evaluating shooting performance as a numerical value ranging from 1 to 10. Further evaluations were held through tri-axial acceleration data recorded at proximal tibial tuberosity beneath each patella on the players' knees, in a procedure in which players were asked to complete four randomly ordered shooting trials of inside and instep kicks with 2-minute resting intervals. Hence, the mainstream data used in consistency calculations are in the form 4 by 1200 matrices (acceleration vs. time) per subject. In order to evaluate the consistency of acceleration data, the mean of the standard deviations (mSD) were calculated, and the associated Pearson-r correlation coefficients were incorporated to obtain mSD vs. skill correlations. As a result, repeatability was found to increase with skill level at z-axis acceleration for instep kicks only. However, it is possible to find the most appropriate orientation (for the two kicks) for meaningful correlations using vector rotations on the 3 orthogonal acceleration data, and this study shows that, after such suitable vector rotations, positive repeatability results could also be acquired for the inside kicks.

Key words: Accelerometry, soccer, repeatability, skill level.

Introduction

Two or three dimensional procedures designed for comparing angular motion can be used effectively to differentiate movement dynamics for several types of soccer kicks. Research has been done employing kinematic analysis to some degree, in order to study multi-joint movements during inside and instep soccer kicks (Asami and Nolte, 1983; Levanon and Dapena, 1998; Nunome et al., 2002; Luhtanen, 1988; Putnam, 1991). One common point of these studies is that, they do not address the very important issue of repeatability.

Accelerometer-based motion analysis methodology has some major advantages compared to the alternatives, which are based on three-dimensional video analysis, and in turn require co-measurement of several anatomical body landmarks. The use of accelerometers makes direct measurement of axial/segmental acceleration possible, which would otherwise only be estimated via computation of the second derivative from position data (Bisseling and Hof, 2006). Additionally they are moderately portable and easy to use in the field settings, compared to video-based systems (Kavanagh, 2006).

Among previous studies making use of accelerometers for motion analysis, determination of spatial-temporal gait variables (Kavanagh, 2006; Mansfield and Lyons, 2003; Moe-Nilssen and Helbostad, 2004; Zijlstra and Hof, 2003), estimation of hip-joint loading patterns (van den Bogert et al., 1996; Zijlstra and Bisseling, 2004), and the assessment of balance and stability during locomotion (Menz et al., 2003; Moe-Nilssen, 1998) have been the major research issues. Recently, a high degree of waveform repeatability seems to have been revealed (Kavanagh et al., 2006) on a framework focusing on the reliability of segmental acceleration measured during gait cycles.

Instep kicks in soccer, are known to be used when the player needs to generate a faster ball speed, nevertheless, the inside kick is considered the most frequently used technique when a shorter and precise pass or shot is required (Nunome, 2002; Lees, 1996). Thus, it can be hypothesized that the inside kick would be superior in terms of consistency, performed repetitively by the same player. Further questions are: (i) If an experienced football player uses a particular strategy to produce his/her best kick, can it be quantified over a suitable method?, and, (ii) Does the skill level of a player affect the consistency between kicks when the same strategy is employed repetitively? Assuming that the associated acceleration pattern has a good correlation with that strategy, knowing the answers to these questions may provide important insights into the assessment of kicking techniques, the evaluation of the players' progress, and possibly the objective selection of talented players not only in the laboratory but also in field settings.

Therefore, the purpose of the present study has been two-fold; (a) to compare the consistency in the lower limb acceleration patterns during inside and instep kicks performed by players with different skill levels, and (b) to investigate the correlation between the subjects' skill ratings relative to their kicking performance, and repeatability of the knee acceleration profile in order to provide a suitable basis for new methods aiming to optimally record and analyse similar conditions.

Methods

Subjects

Thirteen male, club-level soccer players between ages of 15-16 years (mean age: 15.28 ± 0.46 years; height: 1.76 ±

Received: 31 December 2009 / Accepted: 04 May 2010 / Published (online): 01 September 2010

0.07 m ; weight: 64.00 ± 5.17 kg), participated in the study. Skill levels of the players were evaluated by their coach with a numerical value ranging from 1 to 10, regarding the effectiveness of their shooting performance during the trials. The study was conducted in agreement with guidelines and policies of the ethics committee of the Middle East Technical University.

Data collection and preparations

The players were asked to perform inside and instep kicks as powerful as possible using their preferred legs, to the center of the goal, which was located 11 meters in front of them. After warming up and a few prior test kicks, subjects completed four trials consisting of both types of kicks in random order, with resting intervals of 2 minutes between each trial. The Mean score of the trials for each subject was calculated for inside and instep kicks, to be used in statistical analysis. A standard (FIFA) soccer ball was used in all trials. A tri-axial accelerometer (TSD109C, ±5g range, Biopac, USA) was attached to the proximal tibial tuberosity beneath the patella of the subjects' knees where x, y and z axis correspond, respectively to lateral (form right to left), horizontal (from back to forward) and vertical (from up to down) directions of the subjects' tibia (Figure 1). Double sided adhesive tape and elastic straps were used to fix the accelerometer to avoid undesired movement due to skin movement/vibration artifacts at best. The tri-axial (x, y, and z) recording of the acceleration data was started before the kicking action, as the subjects were standing stationary on their feet, and recordings was terminated two seconds after each kick. Acceleration signals were acquired using an analog-to-digital converter card (USB-1608FS, Measurement Computing, USA) at a sample rate of 1000 Hz per channel.

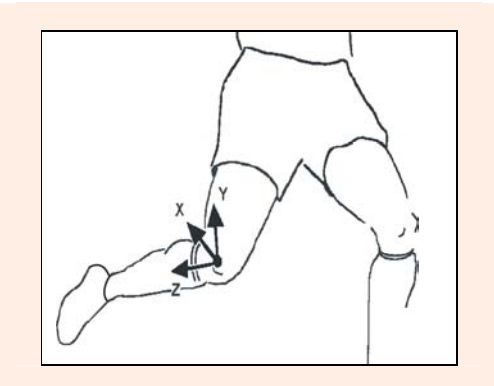

Figure 1. The placement of the three-axial accelerometer on a subject's knee. x, y and z directions are knee to lateral (form right to left), horizontal (from back to forward) and vertical (from up to down) to the subjects' tibia.

Normalization procedures

The normalization procedure for each axis of acceleration data consisted of three stages. In the first stage, the mean value of the first 100 ms of acceleration signal was subtracted from the whole signal, such that during the initial resting condition of the leg, the acceleration signal would be at zero, indicating no acceleration. Secondly, the whole signal was divided by a constant value according to the sensitivity characteristics of the accelerometer, to be able to represent the values in terms of Earth's gravity (g). Finally, normalization along the time axis was performed by shifting data such that the maximum instants get overlapped. The resultant 4 by 1200 acceleration matrices (g vs. ms) corresponding to the 4 trials of each subject were used in consistency calculations. The acceleration signals obtained through the four trials are illustrated in Figure 2, for two players having higher (Skill level: 8) and lower (Skill level: 2) score of mean subjective evaluation on their skill level, respectively.

Calculation of consistency and statistical analysis

Mean of standard deviations (mSD) was used to evaluate the consistency of acceleration data.

The equation (Eq. 1) of mSD is,

$$mSD = \frac{\sqrt{\sum_{i=1}^{m} \sum_{j=1}^{n} (E_{ij} - \overline{E}_i)^2}}{m.n.\max(E_{ij})} \qquad \textbf{Eq. 1}$$

Where m (=1200) is the number of temporal points, n (=4) is the number of acceleration epochs, E_{ij} is the value of the j^{th} acceleration signal at time epoch i, $\overline{E}_i$ is the value of averaged acceleration waveforms at time epoch i.

mSD measures similarity of acceleration waveforms so that zero indicates exactly the same waveforms, corresponding to "no variability" or maximum consistency between the trials. If similarity decreases, mSD increases (corresponding to higher variability or lower repeatability). The logic behind mSD is the same as standard deviation (i.e., mSD is a logical extension of "SD of one channel signal" to "SD of multichannel signal") and amplitude normalization (it is further divided by number of signal points, m-times-n and maximum amplitude of 1200-by-4 acceleration matrix signal, E_{ij}). The aim of the last amplitude normalization was to make the consistency measure (mSD) independent from the signal length, trial count, or the peak acceleration reached by the subject. Furthermore, similar to employing the maximum voluntary contraction for normalization procedures in surface electromyography (sEMG), this amplitude normalization in acceleration signals also makes each repeatability measure comparable between subjects. The mSD values were calculated for all axes of the acceleration signals (x, y and z). For similarity measures, although there exist other methods like variance ratio (Hershler and Milner, 1978) or singular value decomposition (Soylu, 2008), mSD was preferred because it does not require reaching high trial counts during the measurements.

Pearson-r correlation coefficients were also calculated for mSD vs. skill correlation. Even if nonparametric Spearman-r values indicated slightly lower p-values, parametric Pearson-r values were preferred as it provided a worst case condition. Figure 3 shows repeatability indices (mSD) vs. skill graphs for acceleration signals at all x, y and z-axis.

To ensure optimal positioning of the accelerometer, three orthogonal acceleration signals were recorded

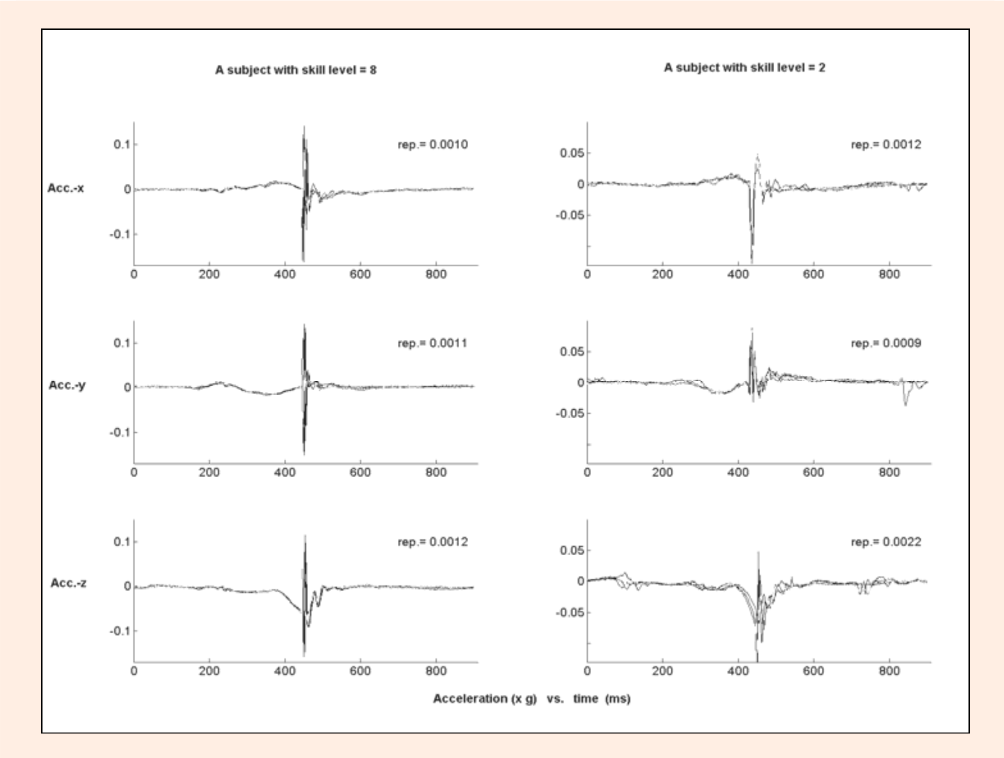

Figure 2. **Acceleration signals (x, y and z) of the two subjects with different skills. On the right upper part of the graphs, repeatabilities (mSD) were shown.**

and some vector rotations were reproduced. Instead of rotating acceleration signals for different possible angles and calculating correlation coefficients, the projections of 3D acceleration signals ($[a_x, a_y, a_z]$) on the unity vector were calculated for different unity 3D vectors $[\sin(\phi).\cos(\theta), \sin(\phi).\sin(\theta), \cos(\phi)]$ (Figure 4), and mSD values of projected accelerations were found for each subject. The reasons of the projection operations instead of vector rotations are (i) to give clear and intuitive descriptions to the reader, and (ii) to use very basic mathematics. The correlation coefficients (mSD vs. skill) were recalculated for many unity vectors that span 3D space. The following equation (Eq. 2) was used for projections for all integer values of ϕ and θ ($0^o<\phi<180^o$ and $0^o<\theta<360^o$) (a_p is dot product of 3D acceleration vector $[a_x, a_y, a_z]$ and unity vector $[\sin(\phi).\cos(\theta), \sin(\phi).\sin(\theta), \cos(\phi)]$).

$$a_p = a_x.\sin(\phi).\cos(\theta) + a_y.\sin(\phi).\sin(\theta) + a_z.\cos(\phi) \quad \textbf{Eq. 2}$$

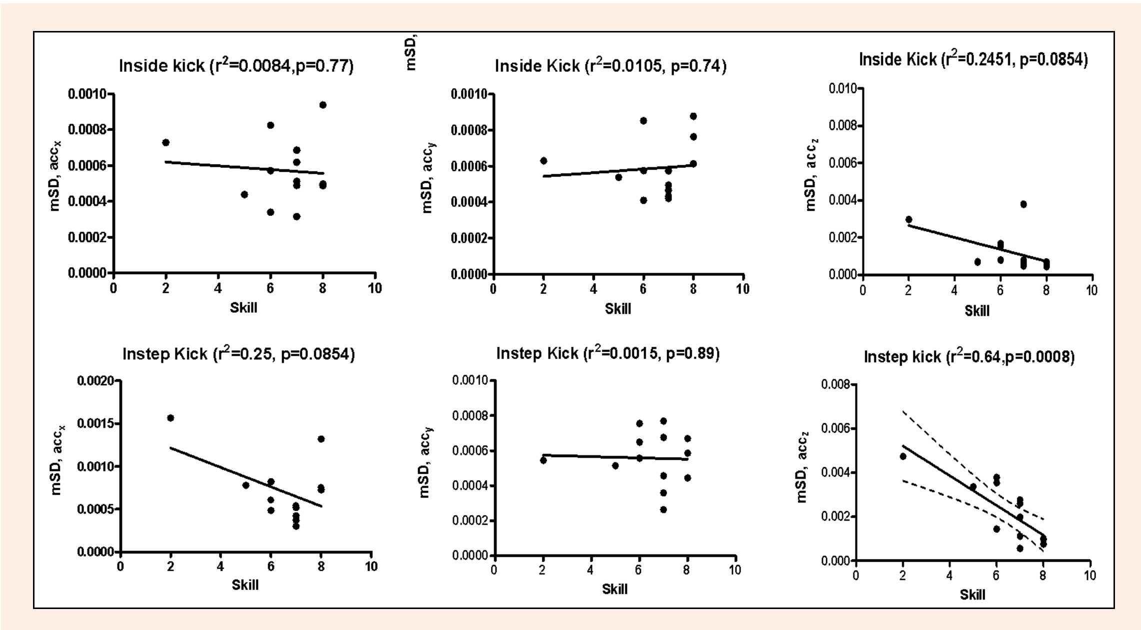

Figure 3. **Repeatability indices (mSD) of acceleration (x, y and z) vs. skill graphs for different shooting techniques. Square of pearson- r values and corresponding p-values are shown on the graphs. 95% confidence intervals are drawn if p-value is less than 0.05.**

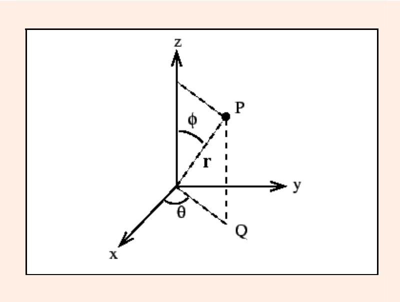

Figure 4. **The vectoral representation of the unity vector (r=[sin(ϕ).cos(θ) , sin(ϕ).sin(θ) , cos(ϕ)]) on the orthogonal x, y and z axis.**

Results

Pearson-r correlation coefficients calculated from 'mSD vs. skill correlation' for trials performed with instep and inside kicks for x, y and z acceleration signals are shown in Figure 3. The only statistically significant result ($p < 0.001$) (Pearson-r = -0.8000) was found for instep kick at z-axis acceleration. Pearson-r correlation coefficients calculated from 'mSD vs. skill correlation' for instep and inside kicks for projected acceleration signals are shown in Figure 5.

Discussion

A primary consideration in functional performance is the ability to successfully complete a specific motor task and perform it consistently (Granata, 2005). Theoretically, even a simple and basic football strike can be performed with different movement patterns without a strict relationship with the player's experience. Therefore, the following question has been raised; Do the players with higher performance levels have also higher knee-acceleration repeatability for instep and/or inside kicks which in turn means that they use a particular strategy to produce the best kick? Figure 2 and Figure 3 give some hints to the answer of the above question: statistical analysis of the data (Figure 3) show that the repeatability (lower mSD means higher repeatability) also decreases with decrease in the skill level from higher to lower score at z-axis for instep kick (Pearson-r = -0.8000, $p < 0.001$). A similarly successful result was found for inside kicks but after suitable vector rotations since for every kick type, optimal recording position is different.

To the best of our knowledge, in the literature "skill vs. acceleration waveform repeatability" has not been investigated via accelerometry. But the articles on "archery skill vs. EMG repeatability" (Clarys et al. 1990; Soylu et al. 2006) have also proved that while the skill level increases, repeatability of the muscular activation pattern also increases. Even if, the present study is focused on the soccer kicks, the results also exhibit a similar correlation between the repeatability and skill level.

When considering these results, other important questions have also been examined: i) "if the accelerometer had been placed on the knee at a different angle, would the same results be found?" and ii) "what is the appropriate angle for the placement of the accelerometer on the knee to obtain higher correlation?" According to the findings presented in Figure 5, the answers to these questions can be explained as follows. If the accelerometer had been placed with a different angle it would have provided the lowest possible correlations: Pearson- r = -0.8350 ($p < 0.05$) for instep and Pearson-r = -0.8250 ($p < 0.05$) for inside kicks. Closer inspection of Figure 5 shows that the

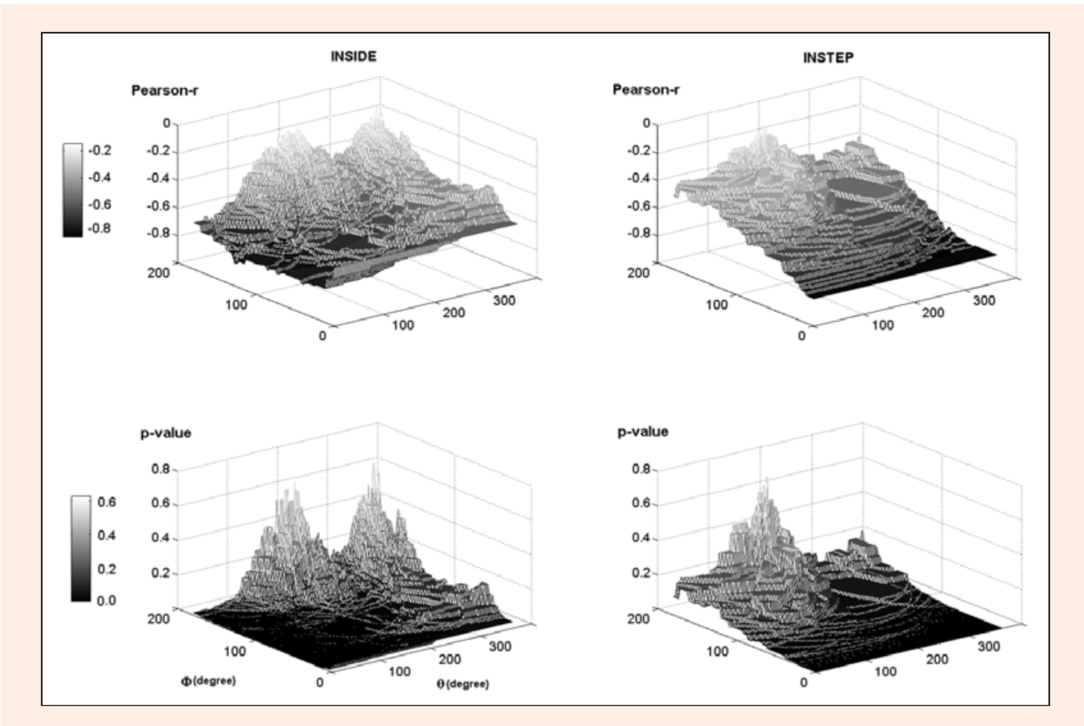

Figure 5. **Pearson-r correlations and p-values for different unity vectors. 64800 (180*360) projected acceleration signals were used for each Pearson-r coefficient and p-value for each kick. Only integer values of ϕ and θ (0^o<ϕ<180^o and 0^o<θ< 360^o) are used in the calculations.**

most appropriate possible accelerometer angle is different for inside (~20°<ϕ<~40° and 0°<θ< ~60°) and instep kicks (~0°<ϕ<10° for any θ°). Note that, even if the most appropriate accelerometer angles are different for two kicks, it is possible to find the best appropriate angles just by using vector rotations since 3 orthogonal (x, y and z) acceleration signals were recorded.

Therefore, the purpose of the present study has been established in two way: one is by comparing the consistency in the lower limb acceleration waveforms during inside and instep kicks and, the other is investigating the correlation between subjective rating scores on skill level and knee acceleration repeatability and by seeking a suitable method for optimal recording of that correlation. Although, there are other body parts involved in kicking action such as foot, knee was chosen in this study as its peak acceleration never exceeded +/- 5g. Another important point in the selection of the knee was also the possible displacement of the accelerometer during kicking due to very high accelerations which is likely to get unreliable recordings. To illustrate, in our preliminary measurements, the peak accelerations of the foot even exceeded ±50g limit because of the saturation in acceleration signal when the foot contacts with the ball.

Conclusion

This study elaborated on knee acceleration repeatability as a function of skill. It appears that the order of the repeatability decreases from a higher to lower score on subjects' skill levels. It is well known that once subjects could produce accurate movements, muscle torques changed with further learning, however, with only slight change in joint kinematics (Young and Marteniuk, 1997). Therefore, the method proposed in this study might be useful as an objective and cost effective assessment that allows the consistency of the action to be interpreted throughout the learning progress. However, more research should necessarily be performed to confirm usefulness of the method for evaluation of skill on individual subjects.

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Key points

- The repeatability of the acceleration waveforms are well correlated with the skill level of the subjects.
- Accelerometry might be used as an objective and cost effective assessment that allows interpreting consistency of the action.

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