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THE APPLICATION OF AN EXPLORATORY FACTOR ANALYSIS TO INVESTIGATE THE INTER-RELATIONSHIPS AMONGST JOINT MOVEMENT DURING PERFORMANCE OF A FOOTBALL SKILL

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ABSTRACT
Many studies have investigated the kinematics of sports skills with the majority describing the kinematics of the technique or investigating significant kinematic variables that affect performance. Many sports skills are complex three-dimensional movements involving many joints. However, few studies have investigated the relationships between kinematic variables during performance of such skills. The aim of this study was to investigate the inter-relationships among three-dimensional kinematic variables during performance of a lofted instep soccer kick. A motion analysis system was used to collect kinematic data for 13 skilled amateur soccer players attempting a standardised lofted instep kick. Three-dimensional angular displacement patterns were reported for the thoracolumbar spine and right hip joints. Two-dimensional angular displacement data was reported for the right knee and ankle joints. An exploratory rather than confirmatory factor analysis was applied, as there is currently no established theory regarding the kinematics of a lofted instep kick. Factors were extracted using the Maximum Likelihood Solution and orthogonally rotated using Varimax with Kaiser normalisation. The inter-relationship among biomechanical variables within the seven extracted factors was analysed with each factor revealing previously unknown inter-relationships among variables for different aspects of the kick. The use of exploratory factor analysis has shown the complex three-dimensional kinematic inter-relationships for a lofted instep kick. An understanding of these relationships could prove useful to coaches when instructing, and in the development of coaching programmes related to the lofted instep kick.

KEY WORDS: Soccer, kicking, three-dimensional kinematics.

INTRODUCTION

The most widely studied skill in football is kicking (Lees and Nolan, 1998), with the majority of studies reporting on the two-dimensional (2D) and three-dimensional (3D) kinematics of the low or maximum velocity instep kick (Barfield et al., 2002; Isokawa and Lees, 1988; Lees and Nolan, 2002;

Lees et al., 2005; Levanon and Dapena, 1998; Shan and Westerhoff, 2005). There are many types of kick used in a game of football, including the lofted instep kick, the aim of which is to propel the ball high and over long distances. Few studies have analysed the 3D kinematics of a lofted instep kick (Browder et al., 1991; Prassas et al., 1990).

An understanding of the biomechanics of kicking can assist the coaching process (Lees, 2003). Coaching experience, combined with knowledge of a mechanical model of the desired performance, is regarded as necessary for a coach to correct performance (Elliott, 2001; Lees, 2002). More studies on the lofted instep kick are needed to provide detailed information on the kinematics of the skill and ensure that existing coaching literature is correct (Prassas et al., 1990). Anderson and Sidaway (1994) analysed the co-ordination of the low instep kick using timing variables and angle-angle plots. Few studies have used a factor analysis (or similar technique) to examine relationships between kinematic variables in kicking (Hodges et al., 2005).

The purpose of this study was to identify and interpret the inter-relationships amongst 3D kinematic variables for a lofted instep kick. As there is currently no established theory regarding the kinematics of a lofted instep kick, an exploratory rather than confirmatory factor analysis was applied to summarise the kinematic data.

METHODS

Thirteen male and female skilled amateur soccer players (23.9 ± 6.1 yrs; 74.7 ± 12.0 kg; 1.73 ± 0.10 cm, previous experience 13.9 ± 6.0 yrs), volunteered for the study. During data collection subjects were required to perform 20 trials of a right-foot lofted instep kick. They were required to take a two-step angled approach of 45 - 60° towards a stationary soccer ball and kick the ball over a 2m high net aiming for a target (which represented a kick of approximately 35m). The emphasis of the task was on height and distance not accuracy. Successful kicks were categorised according to distance, 15- 27.6m, 27.7-34.9m and 35m+. Twelve retro reflective markers were used to define the thorax, pelvis, thigh, knee and foot, two markers were placed on the ball. Subjects were videoed using a four camera (50 Hz) motion analysis system. Up to three trials from each distance category were selected for further processing and analysis.

Video data of each kick from final toe-off of right foot preceding foot-ball impact to end of active follow-through, was digitised and processed using Peak Motus version 7.0. Spatial data was optimally filtered, the level chosen by the Jackson Knee Point Method and all angles calculated relative to a neutral standing posture. Post impact resultant ball velocity and pre impact resultant foot velocity were calculated manually from scaled co-ordinate data. 3D angular displacement patterns were reported for the thoracolumbar spine (relative motion between thorax and pelvis) and right hip joints. 2D angular displacement data was reported for the right knee and ankle joints. Range of motion (ROM) during follow-through for each joint was also calculated.

The kinematic variables for the thoracolumbar spine, right hip, knee and ankle joints chosen for inclusion in the exploratory factor analysis were: peak angular displacements between toe-off and foot-ball impact; angular displacements at toe-off, heel-strike and impact; and, ROM during follow-through. Additionally angular displacement data was time normalised between toe-off and foot-ball impact and timing of peak values were then reported as a percentage of total kick time. Timing of peaks were included in the analysis as were horizontal, vertical and resultant post-impact ball velocities and resultant pre-impact foot velocity. Due to an insufficient number of 35m+ kicks in relation to the number of biomechanical variables, kicks of all distances were included in the exploratory factor analysis.

The factor analysis was carried out using SPSS version 11.0. Factors were extracted using the Maximum Likelihood Solution and orthogonally rotated using Varimax with Kaiser normalisation. Cattell's scree test (Stevens, 1996, Kim and Mueller, 1978) was used to determine the number of factors to be extracted. Examination of the scree plot indicated that no more than seven factors should be extracted. Factors were extracted from the rotated factor matrix by selecting variables with a factor loading of ≥ | 0.4 | for inclusion within that factor (Hair et al., 1998; Stevens, 1996). As a result a few variables were common to more than one factor. Timing of peak hip extension, abduction and external rotation, thoracolumbar spine extension, knee flexion, ankle plantar-flexion and ankle ROM during follow-through and foot velocity were poorly represented in the factor solution. As a result they were omitted from the interpretation of each factor.

RESULTS

Table 1 shows that the first seven factors obtained from the following factor analysis accounted for 67.6% of the variance. Factor one appears dominant, accounting for the largest amount variance (19.87%), subsequent factors account for decreasing amounts.

Table 1. Total variance explained by the first seven factors.

Factor	Initial Eigenvalues		
	Total	**% of Variance**	**Cumulative % of Variance**
1	11.523	19.868	19.868
2	6.304	10.868	30.736
3	5.679	9.791	40.527
4	4.804	8.284	48.810
5	4.115	7.095	55.906
6	3.539	6.101	62.007
7	3.254	5.610	67.618

Factor one (Table 2) was largely influenced by hip rotation and abduction variables. A decrease in hip joint internal rotation at impact and point of maximum internal rotation (heel-strike to impact) was associated with an increase in external hip joint rotation at toe-off, heel-strike and also peak motion (toe-off to heel-strike). Hip abduction angles at point of maximum (between heel-strike and impact) and impact increased along with the hip joint external rotation variables and hip extension at toe-off. The combination of increased hip abduction, external rotation and extension at toe-off indicated that the more hip extension at toe-off and external rotation in the earlier part of the kick (toe-off to heel-strike), the more hip abduction between point of maximum and impact. Decreased impact angles for hip internal rotation, and increased hip abduction and thoracolumbar spine rotation (thorax to right, pelvis to left) angular displacements, are seen to relate to increased knee flexion, at impact. Thus, hip motion prior to and at impact is associated with knee flexion at impact. This association may be result of compensatory movement by the knee to ensure appropriate foot placement at impact.

Factor two (Table 3) indicates that increased knee flexion of the kicking limb at heel-strike is associated with an increase in peak knee flexion (heel-strike to impact) slightly later in the kick. Hip joint abduction at toe-off and heel-strike increases in line with the knee flexion variables suggesting that increased hip abduction in the earlier stages of the kick is related to increased knee flexion later.

Increases in hip joint abduction early on in the kick (at toe-off and heel-strike) also relate to increases in hip abduction/adduction ROM in follow-through. Increases in these hip abduction and knee flexion variables are associated with a decrease in plantar flexion of the ankle throughout the entire kick. A decrease in plantar flexion of the ankle at toe-off is associated with decreased plantar flexion values at heel-strike and impact as well as smaller maximum/minimum values.

Factor three (Table 4) indicates that an increase in thoracolumbar spine adduction (thorax up on right, pelvis down on right) at toe-off is associated with increased thoracolumbar spine adduction throughout the whole kick, and vice versa. In opposition to increases in thoracolumbar spine adduction, hip external rotation at heel-strike and hip abduction at impact decrease. The decreased external hip rotation at heel-strike may be associated with movements of the thorax and pelvic

Table 2. Summary of inter-relationships for kinematic variables in factor one.

Column 1 Variables increasing / decreasing together	**Column 2** Variables increasing / decreasing together & opposite to those in column 1
Peak hip external transverse rotation	Hip internal rotation @ impact
Peak hip abduction	Hip peak internal rotation
Hip transverse rotation ROM during follow-through	
Hip abduction @ impact	
Thoracolumbar spine transverse rotation ROM during follow-through	
Thoracolumbar spine flexion/extension ROM during follow-through	
Hip external transverse rotation @ heel-strike	
Thoracolumbar spine abd/adduction ROM during follow-through	
Hip external transverse rotation at toe-off	
Hip flexion / extension ROM during follow-through	
Hip extension @ toe-off	
* Thoracolumbar spine transverse rotation (thorax to R, pelvis to L) @ impact	
* Hip abd / adduction ROM during follow-through	
* Knee flexion @ impact	

* Variables loading more strongly on other factors

Table 3. Summary of inter-relationships for kinematic variables in factor two.

Column 1 Variables increasing / decreasing together	**Column 2** Variables increasing / decreasing together & opposite to those in column 1
Peak knee flexion	Ankle plantar flexion @ toe-off
Knee flexion @ heel-strike	Min ankle plantar flexion
* Hip abd / adduction ROM in follow - through	Max ankle plantar flexion
Hip abduction @ heel-strike	Time of peak thoracolumbar spine transverse rotation: thorax to L, pelvis to R
Hip abduction @ toe-off	Time of min ankle plantar flexion
	Ankle plantar flexion @ heel-strike & impact
	Time of peak hip internal transverse rotation

* Variables loading more strongly on other factors.

segments that increase thoracolumbar spine adduction in earlier parts of the kick. Also, as the side-to-side tilt of the pelvis influences the magnitude of both thoracolumbar spine and hip abduction/adduction a relationship between the movements of these joints is perhaps logical. The specific variables included in factor three suggest that only hip abduction/adduction variable related to spine adduction was hip abduction at impact.

Thoracolumbar spine extension angles dominate factor four (Table 5), where a decrease/increase in spine extension at toe-off is associated with a change at point of maximum extension (toe-off to heel-strike) and at heel-strike.

The inter-relationships with the remaining variables suggest, that a decrease in thoracolumbar spine extension at toe-off, point of maximum, and at heel-strike is associated with an increase in hip extension at point of maximum (between toe-off and heel-strike) and at heel-strike.

Increases in ball velocities were associated with decreased peak hip extension, hip extension at heel-strike and peak hip external rotation for factor five (Table 6). As peak hip extension and external rotation occur between toe-off and heel-strike, these associations suggest a decreased external rotation in the earlier part of the kick immediately followed by a shorter backswing of the kicking leg as a result of decreased peak hip extension are related to increases in ball velocities. A decrease in external hip rotation suggests a reduced rotation away from the intended flight of the ball in the early stages of the kick is related to increases in ball velocities and reductions in hip extension but external hip rotation variable only accounted for 17.7% of variance on this factor.

Table 5. Summary of inter-relationships for kinematic variables in factor four.

Column 1 Variables increasing / decreasing together	**Column 2** Variables increasing / decreasing together & opposite to those in column 1
Hip extension @ heel-strike	Peak thoracolumbar spine extension
* Peak hip extension	Thoracolumbar spine extension @ toe-off
	Thoracolumbar spine extension @ heel-strike
	Knee flexion / extension ROM in follow-through

* Variables loading more strongly on other factors.

Table 4. Summary of inter-relationships for kinematic variables in factor three.

Column 1 Variables increasing / decreasing together	**Column 2** Variables increasing / decreasing together & opposite to those in column 1
Thoracolumbar spine adduction (thorax up on R, pelvis down on R) @ toe-off	* Hip external transverse rotation @ heel-strike
Min thoracolumbar spine adduction (thorax up on R, pelvis down on R)	* Hip abduction @ impact
Thoracolumbar spine adduction (thorax up on R, pelvis down on R) @ heel-strike	
Max thoracolumbar spine adduction (thorax up on R, pelvis down on R)	
Thoracolumbar spine adduction (thorax up on R, pelvis down on R) @ impact	

* Variables loading more strongly on other factors.

Table 7. Summary of inter-relationships for kinematic variables in factor six.

Column 1 Variables increasing / decreasing together	**Column 2** Variables increasing / decreasing together & opposite to those in column 1
Peak thoracolumbar spine transverse rotation (thorax to L, pelvis to R)	* Time of min thoracolumbar spine adduction (thorax up on R, pelvis down on R)
Thoracolumbar spine transverse rotation (thorax to L, pelvis to R) @ toe-off	
Thoracolumbar spine transverse rotation (thorax to L, pelvis to R) @ heel-strike	
Hip abd / adduction ROM in follow-through	

* Variables loading more strongly on other factors.

Table 6. Summary of inter-relationships for kinematic variables in factor five.

Column 1 Variables increasing / decreasing together	**Column 2** Variables increasing / decreasing together & opposite to those in column 1
Resultant ball velocity	Peak hip extension
Horizontal ball velocity	* Hip extension @ heel-strike
Vertical ball velocity	* Peak hip external rotation

* Variables loading more strongly on other factors

Variables relating to orientation of the thoracolumbar spine during the initial part of the kick dominate factor six (Table 7). The inter-relationships indicate that increased thoracolumbar spine transverse rotation (thorax to left, pelvis to right) at toe-off is associated with increases at peak (toe-off to heel-strike) and heel-strike. Increases in spine rotation in the first part of the kick are also seen to relate to increased hip abduction/adduction ROM in follow-through. Time of minimum thoracolumbar spine adduction (thorax up on R, pelvis down on R) occurs just after toe-off and decreases in association with increases in spine rotation variables. The greater the spine rotation at toe-off the closer to toe-off minimum spine adduction occurs.

For factor seven (Table 8), the inter-relationships indicates that the greater the knee flexion at toe-off the greater the knee flexion at impact (or vice versa), suggesting that a player who requires more or less knee flexion at impact may also be instructed to increase or decrease knee flexion (as appropriate) at toe-off. However, a decrease in knee flexion at toe-off indicates the players are taking a longer final stride prior to kicking leading to a relative increase in kick time allowing more time to swing the kicking leg backwards and to extend the knee at impact. An increase in knee flexion angles was associated with a delay in the time of maximum thoracolumbar spine adduction (thoracolumbar spine remained adducted the entire kick). The further the pelvic segment was orientated down to the right (thorax up on right, pelvis down on right) decreased the distance between the pelvis and the ground, and more knee flexion may have been required to clear the foot prior to impact.

Smaller hip joint flexion and thoracolumbar spine flexion and transverse rotation values at impact corresponded to a kick with increased knee flexion at impact, indicating that the body will be in a more upright and more forward position. The time of minimum thoracolumbar spine adduction was inversely related to time of maximum thoracolumbar spine adduction and knee flexion.

Table 8. Summary of inter-relationships for kinematic variables in factor seven.

Column 1 Variables increasing / decreasing together	**Column 2** Variables increasing / decreasing together & opposite to those in column 1
Knee flexion @ toe-off	Hip flexion @ impact
Knee flexion @ impact	Time min thoracolumbar spine adduction (thorax up on R, pelvis down on R)
Time max thoracolumbar spine adduction (thorax up on R, pelvis down on R)	Thoracolumbar spine transverse rotation (thorax to R, pelvis to L) @ impact
* Knee flexion / extension ROM in follow-through	Thoracolumbar spine flexion @ impact

* Variables loading more strongly on other factors.

DISCUSSION

Kicking is a complex three-dimensional movement and exploratory factor analysis has proved an effective technique for describing and summarising the inter-relationships between the spine and hip, knee and ankle joints of the kicking limb for a lofted instep kick. Interpretation of the seven factors has provided a practical insight into the complexities of the inter-relationships apparent in lofted instep kicking.

Combined with knowledge of ideal characteristics of lofted instep kick performance, the identification of specific associations between similar or different joints in varying planes of motion is of potential benefit to a coach when attempting to improve a player's technique. Interpretation of the factors has allowed the identification of similar variables that increase (or decrease) in association with each other for every measurement throughout the entire kick. If a coach requires a performer to increase or decrease the magnitude of a specific movement at some later point in the kick, knowing these associations indicates whether increases or decreases in the same type of movement earlier in the kick is likely to contribute to the desired response. Knowledge of these associations will remove the need for the coach to make assumptions regarding the inter-relationships amongst movement patterns and stop erroneous feedback being provided in an attempt to correct the motion.

Likewise, knowledge of positive and negative associations among variables for different joints and / or planes of motion, for similar and opposing phases of the kick, also identified in the preceding analysis, are potentially useful to a coach. These inter-relationships indicate which other movements are likely to be affected if one particular aspect of the kicking action is altered. Having identified a critical aspect of kicking movement to alter, knowledge of other associated movement characteristics provides a coach and performer with the choice of more than one variable to focus on altering. As suggested in the interpretations of some factors, associations between different joints could be due to the influence of a common segment to both, such as the pelvic segment common to thoracolumbar spine and hip joints and thigh common to hip and knee joints, regardless of whether the motion was in the same plane. Further investigation is required to determine the mechanisms of these inter-relationships.

Although factor analysis is a non-dependent statistical process, the interpretation of factor five indicated that decreases in peak hip extension just after toe-off and at heel-strike (suggesting a shorter backswing of the kicking leg) are associated with increased ball velocities. Lees and Nolan (2002) reported increased hip (thigh-trunk) ROM for instep kicks under speed compared to accuracy conditions and Lees et al. (2005) found increases in hip (thigh-trunk) ROM to correlate positively with ball velocity in low maximum velocity instep kicking. The contradictions between the literature and the interpretation of factor five could be due to the differing aims of a lofted instep kick compared to a maximal velocity instep kick. In addition, the hip extension variables discussed did not load very high on factor five, peak hip extension and extension at heel-strike accounting for 23.8% and 20.3% of the variance respectively, suggesting they are of limited importance to the interpretation overall. Further investigation of these inter-relationships is warranted for different types of kick and with differing aims, such as maximal distance, speed or accuracy, to understand the associations between hip extension and ball velocity in lofted instep kicking.

Similarly further analysis is recommended to explore the positive inter-relationship between knee flexion at toe-off and impact partially describing factor seven. An increase in knee flexion at toe-off indicates the players are taking a shorter final stride prior to kicking therefore, it is possible that a relatively shorter kick time will result in with less time to extend the knee in preparation for impact resulting in an increased knee flexion at impact. Isokawa and Lees (1988) suggested there might be two types of kicking patterns for a one-step instep kick. The first involving a large backswing and longer kicking time, the second a small backswing with the lower limb moved forward sharply by knee extension and shorter kicking time. The inter-relationships amongst variables in factor seven suggests two types of kicking action, although further investigation is needed on of expert technique to determine this definitively.

In combination with the existing coaching literature and developments in defining an 'ideal' kinematic model of a lofted instep kick, the inter-relationships among variables identified using factor analysis may be used to aid the development of coaching programmes and coaching points. Such knowledge proving particularly useful if the kinematic variables of interest are difficult to observe or control by the performer, the developed coaching points could then be based on other variables that inter-relate with those deemed critical to performance.

CONCLUSIONS

The application of an exploratory factor analysis to 3D biomechanical data has revealed previously unknown inter-relationships among variables for different aspects of a lofted instep kick. Interpretation of the factors has shown in detail, the complex inter-relationships that exist. An understanding of these relationships could prove useful to coaches when instructing, and maybe useful in the development of coaching programmes related to the lofted instep kick.

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KEY POINTS

- Motion analysis of lofted instep kick.
- Inter-relationship among biomechanical variables within 7 factors analysed.
- Each factor revealed previously unknown inter-relationships among variables for different aspects of the kick.
- understanding these relationships could prove useful to coaches in the development of the lofted instep kick.

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