THE KICKING FOOT SWING PLANE IN RUGBY PLACE KICKING

Neil E. Bezodis[1], Alexander P. Willmott[2], Alexandra Atack[1] and Grant Trewartha[3]

School of Sport, Health and Applied Science, St Mary's University, Twickenham, UK[1]
School of Sport and Exercise Science, University of Lincoln, UK[2]
Sport, Health and Exercise Science, University of Bath, UK[3]

This study aimed to determine the planarity of the kicking foot path in experienced rugby place kickers and to assess the effect of different data treatment methods on measured swing plane variables. Thirteen kickers completed a series of kicks and a least squares plane was fitted to the kicking foot CM trajectory throughout various lengths of the downswing using orthogonal regression. The foot path was typically planar for the last 1.25 m of the downswing. The swing planes were inclined at 50.0 ± 4.2° to the horizontal and the line of intersection between the swing planes and the global horizontal plane was directed 22.3 ± 3.5° right of target. It was proposed that swing planes should be fitted to data sampled at equal spatial divisions and that kicking foot swing planes could offer a useful context for understanding more about proximal technical factors in place kicking.

KEY WORDS: biomechanics, football, kick, orthogonal regression, planarity.

INTRODUCTION: Place kicking success plays a vital role in the outcome of modern rugby union matches. In the knockout stage of the 2011 Rugby World Cup, the results of four of the eight games could have differed if the losing teams' kickers had achieved place kicking success percentages of (at most) 75%. Despite this importance, there exists very little biomechanical research focussed on rugby place kicking technique. The success of any ball kicking action is directly determined by the velocity of the foot at ball contact and the mechanical properties of the foot-ball collision. The foot is the endpoint of a linked-segment system, and whilst the abundance of soccer kicking research suggests that there are many technical factors which affect the velocity of this endpoint (see Lees et al., 2010 for a review), the kicking foot trajectory represents a combination of these proximal degrees of freedom that more directly influences ball flight. Evidence from coaching sources proposes that, if viewed from above, the kicking foot trajectory around ball contact should be relatively straight towards the posts; for a right-footed kicker it should ideally follow more of a J-shape© (Alred, 2005) than an (inverted) C-shape© (Alred, 2005) during the downswing and follow through. Identifying and understanding the path of the kicking foot allows subsequent rugby place kicking research focussing on joint kinematics and kinetics higher up the linked-segment system to be placed in appropriate context, and ultimately for these combined technical factors to be investigated in relation to successful performance.
Much like the foot during a kick, a golf club acts as the distal end of a complex linked-segment system, and the trajectory of a golf club has been considered using the concept of a 'swing plane' for over 50 years. This has recently been extended to other 'hitting' sports such as field hockey (Willmott & Dapena, 2012) and also to soccer kicking (Alcock et al., 2012). Whilst it is accepted that the entire swing is not planar in golf, the clubhead appears to be planar during the important phase around ball contact in skilled golfers (Kwon et al., 2012). The aim of this study was to determine the planarity of the kicking foot trajectory during a rugby place kick, and if this trajectory could be considered planar, to describe the swing plane properties of experienced kickers. A secondary aim was to assess the effects of two different data treatment approaches prior to fitting the plane.

METHODS: Following ethical approval, 13 male place kickers at playing levels ranging from community to age group international level (mean ± SD: age = 20 ± 2 years; mass = 84.2 ± 9.5 kg; height = 1.82 ± 0.07 m) provided written informed consent to participate. Each kicker wore their own boots with moulded studs and, following a self-directed warm-up, performed a series of five or six place kicks using a size 5 match ball (Gilbert Virtuo) placed to their preference on their personal kicking tee on a rubber surface. All kicks were aimed towards a net (1.25 m wide × 2.20 m high) located 2.0 m in front of the kicking tee from which a vertical target was suspended to represent the target line (i.e. centre of the posts).

Kinematic data (240 Hz) were collected in Nexus software (v. 1.8., Vicon©, UK) using 10 or 11 Vicon© MX3 and MX3+ cameras operating at full resolution. The global Y-axis was defined in the direction of the target line from the centre of the kicking tee, the Z-axis was vertical and the X-axis was the cross product of these. For left footed kickers, all X-axis data were inverted and all subsequent results are reported in the convention of a right-footed kicker. The ankle and metatarsal-phalangeal (MTP) joint centres were located during a static trial using reflective markers (25 mm) placed on the medial and lateral malleoli and on the boot at the lateral aspects of the first and fifth MTP joints. Markers were also placed on the boot on the lateral aspect of the mid foot and at the heel, and these two markers along with the lateral malleolus and fifth MTP markers allowed reconstruction of joint centre motion from the dynamic trials. Raw marker data were imported in to Visual3D (v. 5.0., C-Motion©, USA) where any gaps were filled using interpolating cubic splines. The kicking foot centre of mass (CM) was determined using the segmental inertia data of Winter (2005) whilst the centre of the ball was reconstructed from six surface markers. All subsequent analysis took place in Matlab® (v. 7.10, The MathWorks™, USA).

Ball contact (BC) was identified as the frame in which the ball centre first moved by more than the determined precision of the system (0.9 mm). The raw X, Y and Z ball centre displacement time-histories were extracted from the fifth to eighth frames after ball contact as the ball was assumed to remain in contact with the foot for four frames based on pilot investigations. These ball centre displacement data were then individually fitted with polynomial functions (linear for X and Y, quadratic for Z), the gradients of which were extracted and used to calculate resultant ball velocity, ball launch angle (in the Y-Z plane, expressed relative to the horizontal) and direction angle (in the X-Y plane, expressed relative to the target line with positive values representing a slice/push to the right for a right-footed kicker).

The kicking foot CM data (equally temporally sampled at 1/240 s) were duplicated and resampled at equal spatial divisions, as used by Willmott and Dapena (2012). To achieve this, the resultant three-dimensional foot CM displacement between frames was determined, a cumulative sum calculated, and these data were fitted with an interpolating cubic spline which was evaluated at every 0.05 m interval back from BC. A value of 0.05 m was chosen since it corresponded closely to the mean displacement between each 240 Hz frame between support leg contact and BC. This yielded two representations of the continuous kicking foot CM trajectory: one sampled at every 1/240 s in time and one sampled at every 0.05 m in displacement. These two sets of three-dimensional coordinates were duplicated several times and subsequently reduced to different lengths from 2.00 to 0.25 m prior to ball contact at 0.25 m intervals (or as close as possible for the equally temporally sampled data). Each data set was then fitted with a least-squares plane using orthogonal distance regression (Willmott & Dapena, 2012). The inclination of the plane relative to the horizontal was determined as the angle between the global X-axis and the line of intersection between the swing plane and the X-Z plane. The direction of the plane relative to the target was determined as the angle between the global Y-axis and the line of intersection between the swing plane and the X-Y plane. Greater inclination values represented an increasingly vertical plane, whilst positive direction values represented a plane directed towards the right of the target (for a right-footed kicker). The RMS difference between each swing plane and the raw foot CM coordinates was also calculated to determine the goodness of fit of each plane. To facilitate appropriate comparisons of planarity between data sets of different lengths, relative RMS values as a percentage of the length of the analysed foot path were determined, and a value of 0.25% was used as a threshold to determine non-planarity (Willmott & Dapena, 2012). All values are presented as group mean ± SD. Pearson's product-moment correlation coefficients (r) were calculated between selected swing plane properties and kick performance measures using the mean values from each kicker.

RESULTS: The resultant ball velocity was 27.6 ± 1.9 m/s. The absolute deviation in the ball velocity vector from the target line in the X-Y plane (i.e. a measure of accuracy) was 3.2 ± 1.6°, whilst the ball launch angle in the Y-Z plane was 30.7 ± 3.8°. Planarity of the kicking foot path, in terms of a relative RMS difference of less than 0.25% between the raw foot CM data and the swing plane, was confirmed from 1.25 m prior to BC (Figure 1). The swing plane properties (inclination and direction) for each of the 0.25 m intervals analysed using both approaches are presented in Figure 2. Swing plane inclination remained relatively constant at approximately 50° from 1.50 m prior to BC whilst swing plane direction remained relatively constant at approximately 22° from 1.50 m prior to BC.

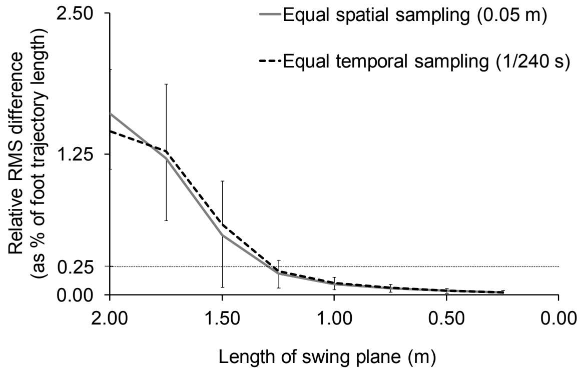

Figure 1. Relative RMS difference between the raw foot CM path and the swing plane at each foot path length for both data treatment approaches (mean and SD).

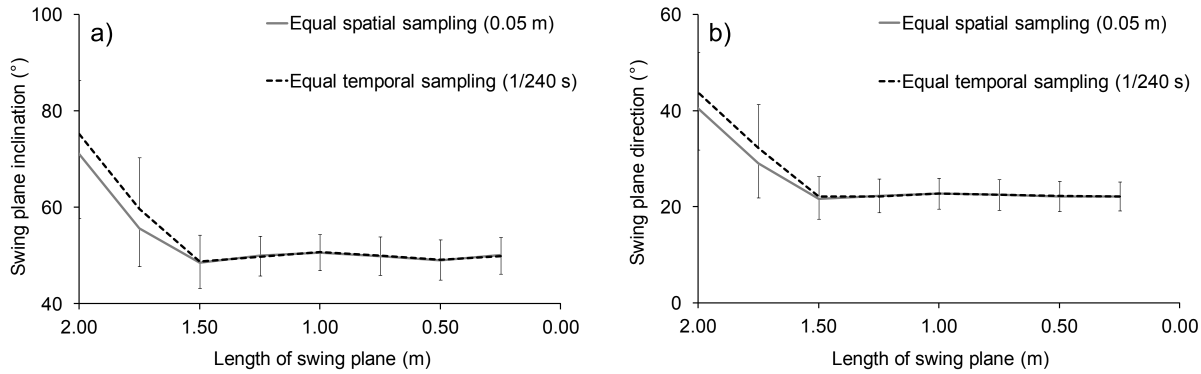

Figure 2. Swing plane a) inclination relative to the horizontal and b) direction relative to the target line at each foot path length for both data treatment approaches (mean and SD).

DISCUSSION: This study determined the planarity of the kicking foot path during a rugby place kick, identified the properties of these planes in experienced kickers, and compared two different data treatment approaches. The ball velocities obtained for these kickers are reflective of their ability level as kickers; the mean value is higher than that (24.5 m/s) of the five university 1st XV place kickers studied by Bezodis et al. (2007). Analysing the swing plane properties of the kickers in the current study therefore yields an appropriate description of accomplished rugby place kicking.

The kicking foot can be considered planar for the last 1.25 m of the downswing prior to ball contact based on the criterion of a relative RMS value of 0.25% of the analysed foot path length (Figure 1). Due to this planar nature of the foot path during the last 1.25 m of the downswing, the swing plane properties were also consistent over this same portion of the trajectory (Figure 2). Using the planes fitted to equally spatially sampled foot path data over 1.25 m, the inclination of the plane relative to the horizontal was 50.0 ± 4.2°, whilst the direction of the swing plane was 22.3 ± 3.5° towards the right of the target (for a right-footed kicker). The plane inclination values are close to those reported in instep soccer kicking (54.8 ± 3.9°) by Alcock et al. (2012). The slightly higher mean value of Alcock et al. (2012) may be due to a different kicking task, the analysis of female participants, or possibly the fact that their swing planes were fitted to the whole kicking leg (i.e. hip, knee and ankle joint centres). In the current study, it was decided to fit the plane to just the distal end of the linked-segment system (i.e. CM of the kicking foot) as it is the foot that actually impacts the ball. Due to this and previously reported non-planarity of the larger system in 'hitting' actions, a single point approach has recently been more commonly adopted (e.g. Kwon et al., 2012; Willmott & Dapena, 2012) than fitting a plane including additional points further up the linked-segment system. Comparing our results with contemporary coaching advice, if viewed in the X-Y plane, a foot trajectory along a more inclined kicking foot swing plane would appear to be a straighter line, closer to the proposed, shallow J-shape© (Alred, 2005) curve through BC, whereas a foot trajectory along a less inclined plane would appear more curved around BC, closer to the (inverted) C-shape© (Alred, 2005). However, the relationship between plane inclination and kick accuracy was weak and non-significant ($r = -0.18$, $p = 0.56$). As all of the kickers exhibited a plane direction angled considerably (22.3 ± 3.5°) towards the right of the target line, considering just the inclination angle of the plane likely leads to an incomplete understanding of the foot path around ball contact and further analysis is required to establish the importance of the foot path and its planarity when considering accuracy in rugby place kicking.

Comparing data treatment methods, the equally temporally sampled and equally spatially sampled data yielded similar planarity, inclination and direction values for the last 1.50 m of the downswing (Figures 1 and 2), but prior to this a greater disparity was evident. For these longer foot paths, the equally temporally sampled data contained relatively more data points from the earlier part of the kicking action where the foot was travelling more slowly, and thus the fit of the plane was more heavily weighted towards this part of the action. This was evident in the systematic difference between the two approaches in plane inclination and orientation prior to 1.50 m (Figure 2). However, as there were still small differences in plane properties at all trajectory lengths between the two approaches, it is proposed that no matter how long the trajectory is, fitting a swing plane to the equally spatially sampled data provides a more appropriate fit that is equally weighted across the entire trajectory.

CONCLUSION: This study identified that the path of the kicking foot CM is planar for the final 1.25 m of the downswing prior to ball contact during a rugby place kick. The methods used to sample the data to which the plane was fitted were shown to affect the properties of the plane, particularly when fitted over longer parts of the kicking action, and the use of equally spatially sampled data was supported. The properties of the swing planes of experienced kickers were described and these offer a potentially useful means of providing endpoint context to joint and segment mechanics from higher up the linked-segment system, potentially in questions related to variability and coordination.

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