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The Effects of Different Instep Foot Positions on Ball Velocity in Place Kicking

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Abstract. To investigate the effects of different instep foot positions relative to the kicking tee on resultant ball velocity, three male subjects were used to carry out the experiment. Four different foot placement conditions were used to help investigate differences in ball velocity. The Vicon 3D analysis system was used to collect angles and moments of the lower joint extremities along with the rugby ball positions. By using the BodyBuilder software, we were able to analyse the data. The results suggested that there were no significant differences in ball velocities across the different conditions within each subject. This was shown by the similarities in the trajectories of the hip and knee angles, and knee moments. Environmental factors and participants factors which may affect the results were also discussed.

Keywords: Rugby, biomechanics, place kicking

1. Introduction

Rugby union is New Zealand's most predominant national sport. Place kicking in the sport of rugby union is a large part of the game, and many hours of training and practice are undergone in perfecting the technique. Yet professional place kickers have little knowledge about what the best actu1al technique is. Rugby union place-kicking technique remains largely unexplored by sports biomechanists, except for a two-dimensional analysis by Aitcheson and Lees [1]. Many two dimensional sagittal plane studies of football kicking have been undertaken, but Rodano and Tavana [14] found that significant differences have been found in linear and angular speeds of joints involved in kicking between two and three dimensional analysis. This suggests that movement occurs in at least one of the non-sagittal planes, which reinforces the hypothesis by Lees and Nolan that a three-dimensional analysis is needed to measure accurate kicking techniques. Bezodie et al used three dimensional analysis techniques to investigate how the non-kicking side arm contributed to the generation and control of whole body angular momentum during rugby place kicking, but still did not investigate the actual mechanisms involved in the kicking technique process.

Place kicking for maximal resultant ball velocity occurs many times during a rugby union game. Instep kicking involves a series of motions that include an initial address to the ball, planting of the support leg beside the ball, and striking the ball with the instep of the kicking foot ([5], [9]). During this type of kicking, the planting leg acts as the axis of rotation for the swinging leg [4]. The generation of kinetic energy begins at the hip, and as the swinging leg comes around, a sequential transfer of momentum from the hip segments to the foot segment which causes a proportional increase in foot speed [10]. Angular momentum is a variable that provides a way to measure the quantity of rotational motion. The angular momentum of any rotating body is a product of its moment of inertia and its angular velocity. There are many inferences that mention the importance of all segments in the body in their contribution to kicking technique, but no studies have investigated the segmental contributions to the generation of angular momentum during kicking [6].

For a competitive player, their ability to achieve a greater distance in place kicking is determined by how efficient they are at transferring kinetic energy from the body to the ball. The ability of the players to be efficient through the kicking motion should maximize ball speed, and as speed of an object is directly related to the distance it travels, it shows that maximal speed is required for optimal distance. The optimal place kick is defined as, "maximal ball velocity, whilst maintaining maximal kick accuracy." Both Barfield [4] and Harrison & Mannering [7] found that the mechanics of instep kicking are critical in determining kicking

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performance, and that the position of the plant leg from the ball and the forces generated by the plant leg are components that affect the resulting ball speed and trajectory. This is because the planting leg generates a large ground reaction force in three different planes of motion; vertical, medial-lateral, and anterior-posterior, which provides support for the kicking leg. Harrison & Mannering [7] found in their study that the participants' plant legs were closer to the ball when kicking with their dominant leg. Asami et al [2] and Lees & Nolan [12] both proposed that when accuracy demand is placed upon a kicker, ball speed has been found to fall by between 20-25% from maximal values. Lees & Nolan [12] also found that ball speed is influenced by trunk segment rotation around longitudinal axis.

The purpose of this study was to examine the effects of instep foot placement position relative to the ball, on the resultant ball velocity, by using the Vicon 3D Motion Analysis System, and Plug-in Gait Model. We were interested in studying various foot placement positions, relative to the ball and tee, as we wanted to broaden the knowledge of rugby place kicking, as there has not been much prior information about it. A full-body kinematic model was recently applied to the study of instep football kicks, but there has been no such research for rugby place kicks. The action is similar between football kicking and rugby place kicking, so many of the articles found in our study are references from football kicking techniques. The independent variable that we used in our study was the instep foot positioning, while the dependant variable was the resultant ball velocity. We hypothesised that maximal ball resultant velocity would be generated when the positioning of the foot was next to the ball, as opposed to wider, in front of, or behind the ball. Also we predicted that a decrease in resultant ball velocity would be shown when the foot was positioned wider of the ball and tee position, as the kicker would be more concerned with accuracy. This supports the study by Lees & Nolan [12] in that when accuracy demand is placed upon a subject, their ball speed reduced by 20-25%.

2. Methods

2.1. Participants

Three university male kickers (mean age 20.3). Each subject had some experience in rugby kicking.

2.2. Procedures

As part of their warm up, subjects performed three to five practice trials outside to acquaint themselves with the testing equipment and be able to kick the ball inside the net provided. Fourteen spherical markers were attached to specific anatomical landmarks on the lower extremity of participants for use with the plug-in-gait model (RTOE, LTOE, RANK, LANK, RTIB, LTIB, RKNE, LKNE, RTHI, LTHI, RASI, LASI, RPSI, LPSI). Two markers were also attached to either side of the ball to track its velocity and movement. The centre of the ball was found with adding the position of the two markers and dividing that by two. Ball contact was determined from initial displacement of the centre of the ball.

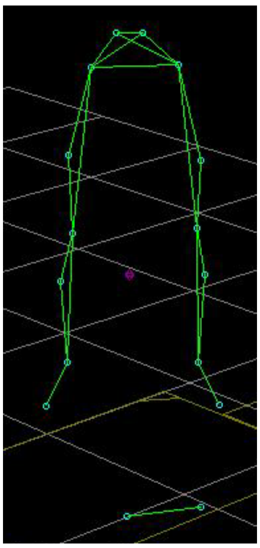


Figure 1. View of markers

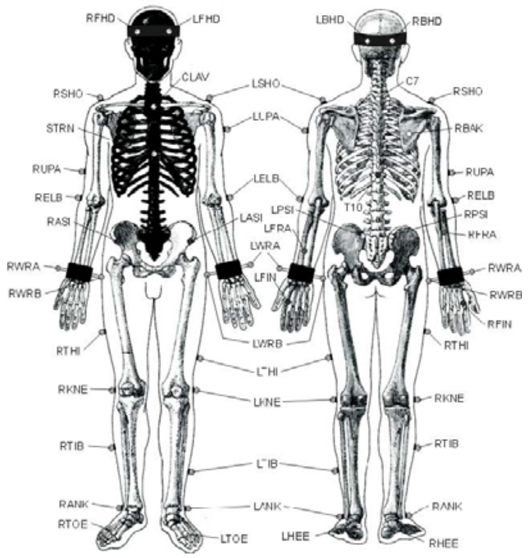


Figure 2. Plug in gait model

After calibrating the Vicon system and the eight cameras, the ball was placed in an area where all the cameras could best view it. From the ball and tee position, four different instep foot positions were marked on the floor with tape so the subjects knew where to put their instep foot each time. The first position was marked 30 cm to the left of the ball which was called “Next to” in our trials. Other positions were marked 30 cm to the front, back or to the left of the “Next to” position and were named, “In Front”, “Behind” and “Wide” respectively.

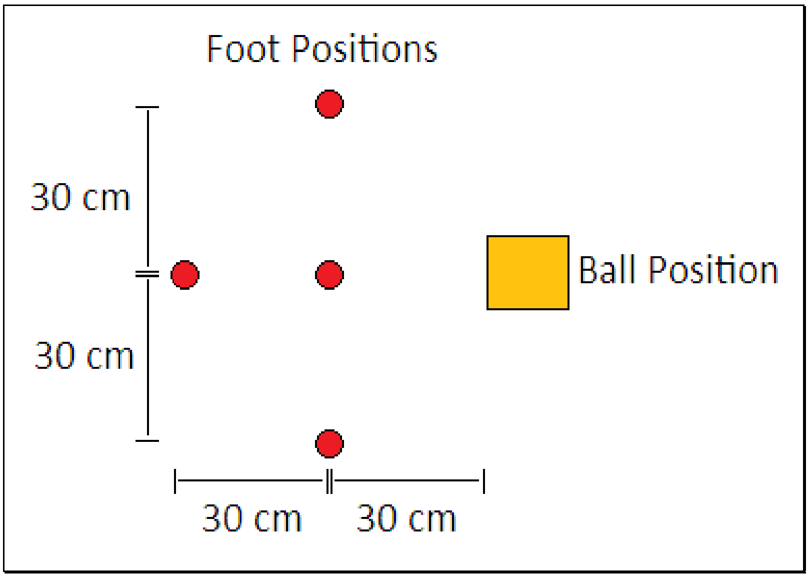


Figure 3. Foot positions in relation to ball position

The net was then placed in front of the ball so when the ball was kicked, the net would catch it. The net was used to protect the expensive cameras and computers. Before any kicking trials were recorded, a static trial of the participants and the ball was recorded to check that all markers were visible. This enabled us to label each marker correctly. Each participant then completed three good trials of each condition, which equalled twelve trials in total.

2.3. Data collection

Kinematic data from each participant were recorded in an indoor gait laboratory using an eight camera Vicon ™ 612 motion analysis system sampling at 250 Hz and calibrated to the manufacturer’s instructions.

Figure 4. Experiment setup side view

Figure 5. Experiment setup front view

2.4. Data reduction

For each successful trial, three-dimensional coordinates for each of the reflective markers were reconstructed using workstation software. The markers trajectories of each trial were checked and missing markers were filled to complete the trajectory, so that no data was missing.

Using the set formulas in body builder we found variables such as knee and hip angles and moments in the X, Y, and Z directions for each frame and outputted the variables of all the trials into Excel files. From the two ball positions we were able to calculate the centre, and velocities were calculated from this.

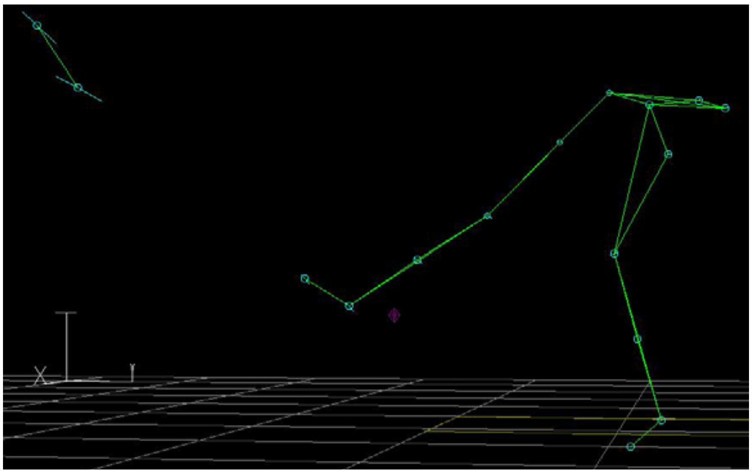


Figure 6. A kicking frame demonstrated via the Vicon system

From the data we were able to find variables such as maximum and minimum knee angles, hip angles, and knee moment. In addition we found the knee and hip angles at initial ball contact, and also the knee moment. Then we compared these values between the different instep foot positions to find similarities and differences. This allowed us to find the effects these different instep positions had on the velocity of the ball.

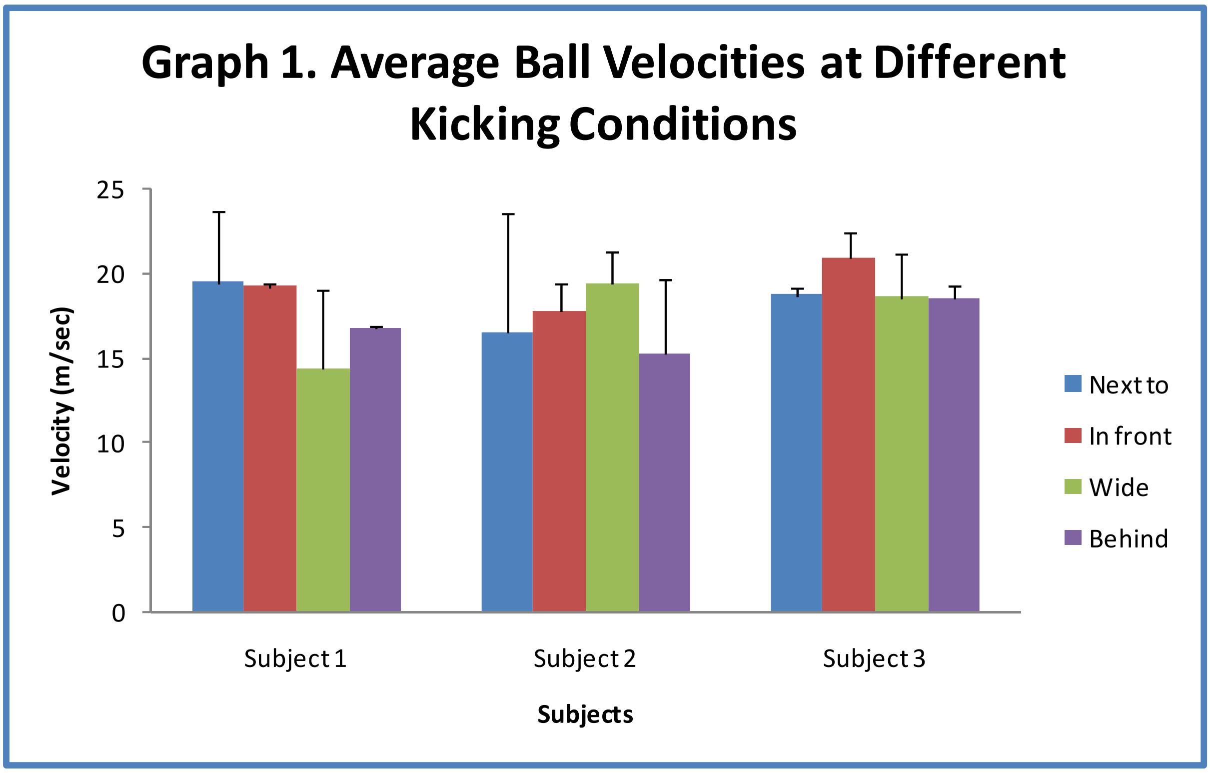
2.5. Statistical analyses

We used a two-tailed t-test to compare variables between the various conditions, with statistical significance set at $P < 0.05$.

3. Results

3.1. Ball velocities

Looking at Graph 1, the ball velocities showed minor variances across the various kicking conditions. The biggest difference was shown in subject 1 between “Next to” and “Wide” (5.10 m/sec). Subject 3 showed the most consistent results, with a range between 18.5 m/sec and 20.86 m/sec. There were no clear patterns shown when comparing the different kicking conditions across the three subjects.



Graph 1. Average ball velocities at different kicking conditions

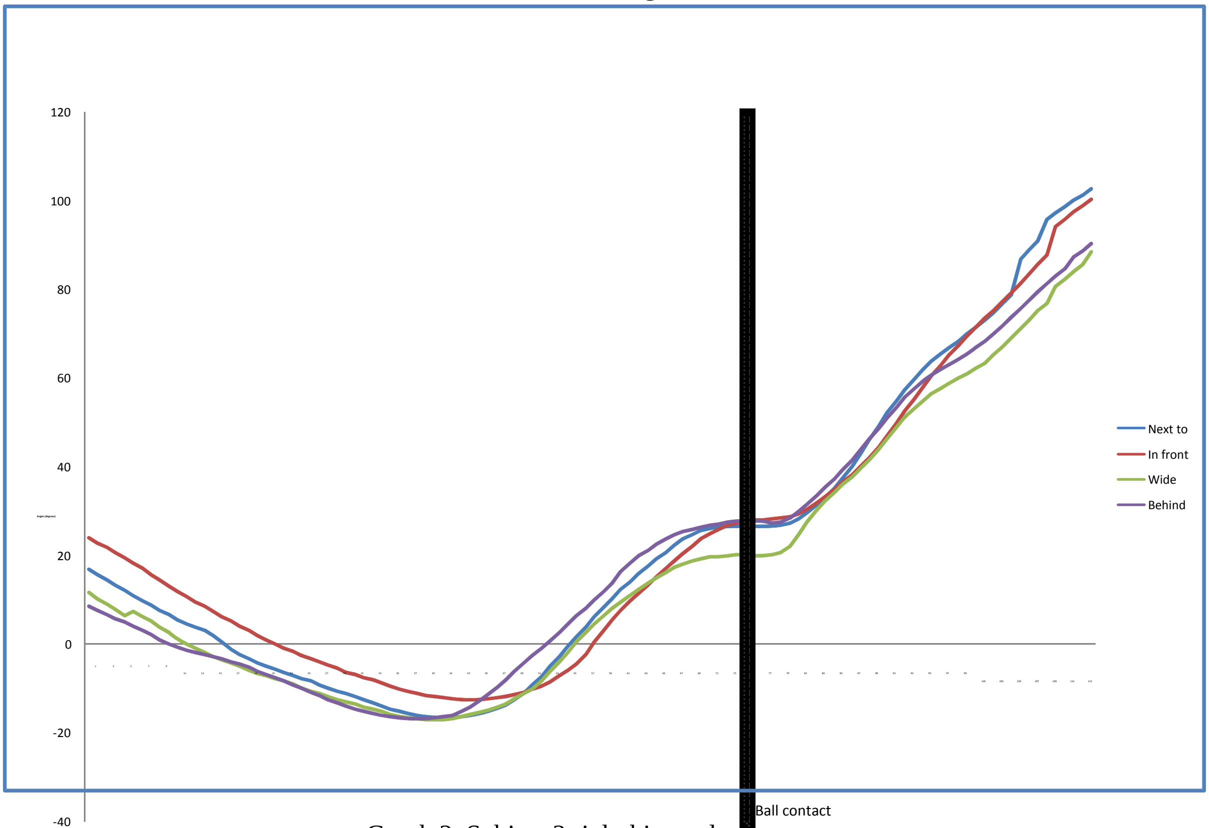
Table 2 displays a t-test which compares the data of various kicking conditions amoung each subject. The majority of the data displayed non-statistically (> 0.05) significant results. The only significant comparion was shown in subject 1, which compares “In Front” to “Behind” (P-value < 0.05). From the t-test our results conclude that ball velocity is not affected by the different kicking conditions.

Table 2. Comparisons of Different Kicking Conditions

T-TEST (P - values)						
	N vs I	***N vs W***	***N vs B***	***I vs W***	***I vs B***	***W vs B***
Subject 1	0.92	0.28	0.38	0.23	0.01	0.46
Subject 2	0.77	0.52	0.76	0.49	0.52	0.10
Subject 3	0.10	0.93	0.80	0.43	0.16	0.98

3.2. Hip angles

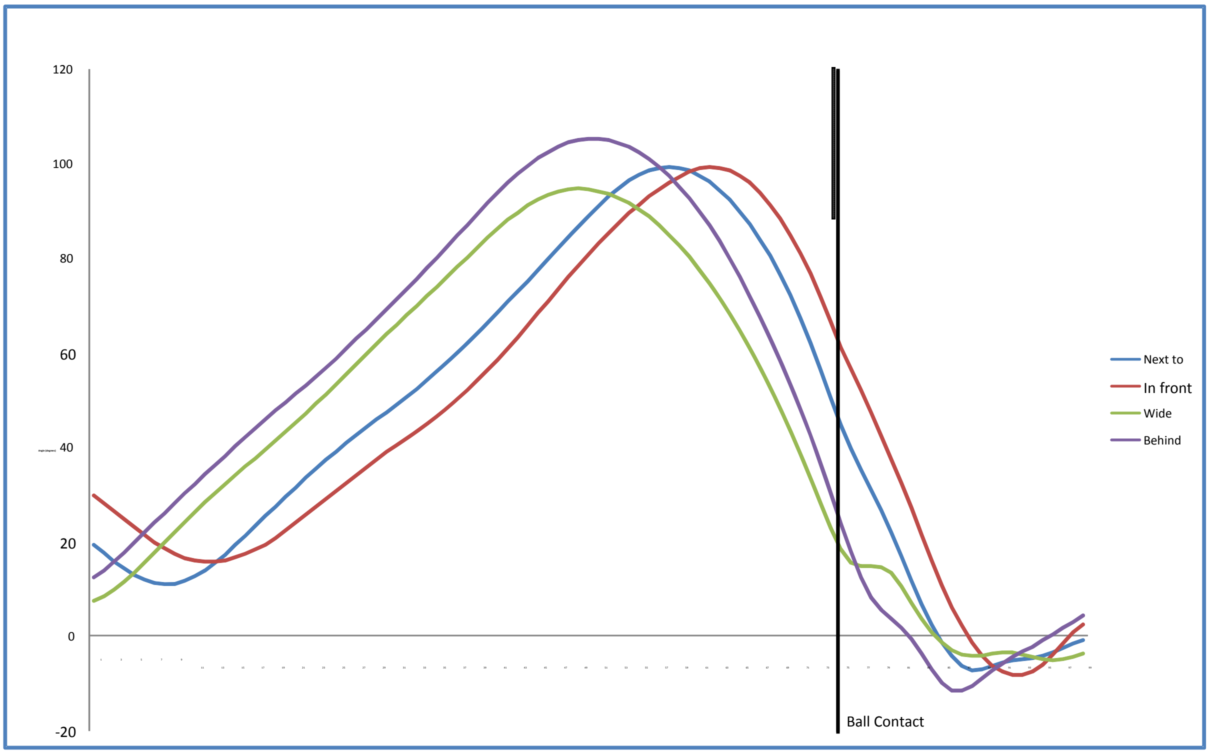
Looking at the trajectories of the right hip angles (Graph 2), similarities were shown at the different kicking conditions across all three subjects. The majority of the differences were shown at ball contact, where adjustments of the leg were made to make successful contact. The “Wide” condition seemed to have the smallest hip angle at contact, with the other conditions being quite similar. From the hip angle graphs, no clear differences were shown between the different kicking conditions.



Graph 2. Subject 2 right hip angles

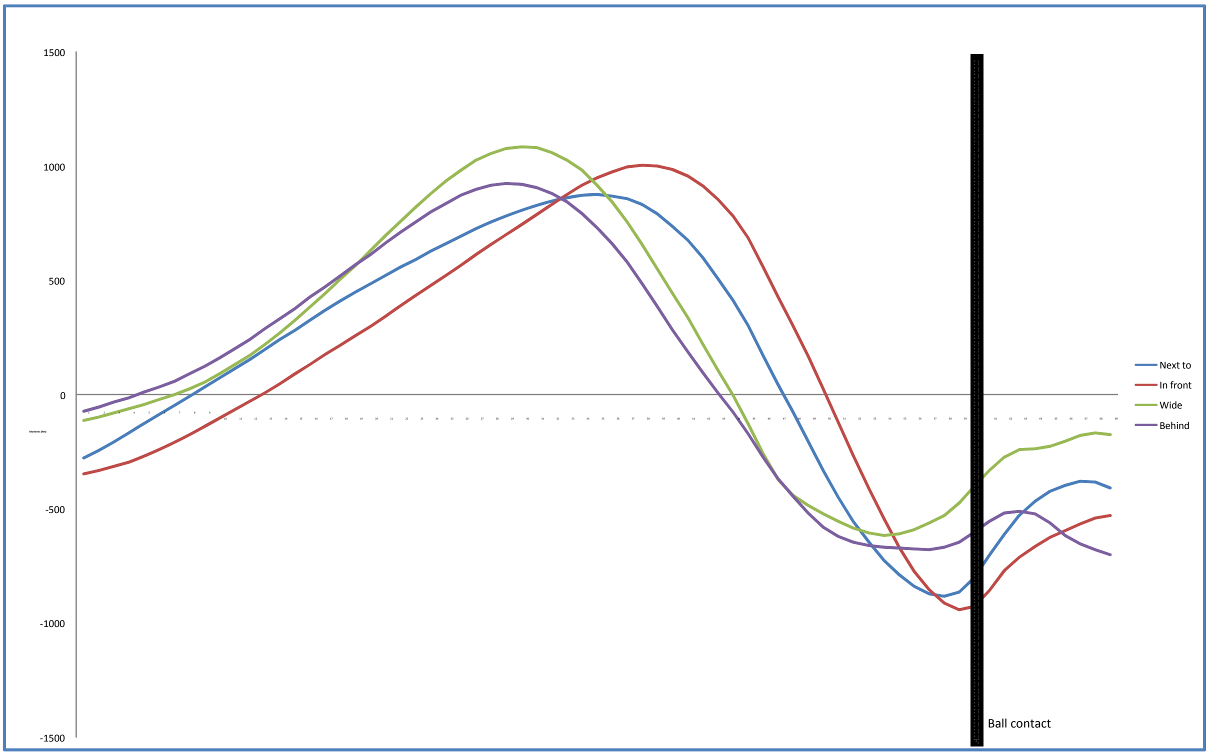
3.3. Knee angles

The knee angle trajectories (Graph 3) showed a bit more variance than the hip angles, but the trajectories were still similar across the different kicking conditions within each subject. Patterns were shown, in which the knee angles at contact from greatest to smallest were “In front”, “Next to”, “Behind”, and “Wide” respectively. This pattern is explainable, as stepping “In front” would shift the body forward creating less time for the knee to fully extend, and hence displays the greatest angle at contact. When stepping “Wide”, greater time is created for the knee to fully extend as it has to reach out far in order to successfully make contact with the ball. The knee angle while stepping “Behind” is similar to “Wide”, as the body is prepared earlier to allow for greater knee extension at ball contact. From the graphs, the knee angles developed trajectories which could correlate with the ball trajectory.



Graph 3. Subject 1 right knee angles

3.4. Knee moments



Graph 4. Subject 1 right knee moments

The knee moments (Graph 4) showed similarities in trajectories across the different kicking conditions within each subject. A lot of the differences were shown at contact, where more concentration may have been placed upon foot placement rather than maximum kicking. At contact the conditions "Wide" and "Behind" showed the greatest moments and "In font" the smallest. There were no clear patterns demonstrated across the different conditions when analysing the subjects.

4. Discussion

Due to the very limited previous knowledge and research on the place kicking techniques, we attempted to broaden the knowledge in this critical aspect of the modern game of rugby union. This study was conducted to examine the effects of different instep foot positions on the resultant ball velocity, using the Vicon 3D Motion Analysis System. It was hypothesized that the maximal ball resultant velocity would be generated when the positioning of the foot was “next to” the ball, as opposed to the other conditions (wide, in front, and behind). However, our hypothesis was incorrect as we found that there was no ideal instep foot position that alters ball velocity. This was shown as all conditions gaining similar velocities and showing statistically non-significant results (p-value > 0.05). However, this was not the case in other studies, Ball [3] found that there is an optimal foot position relative to the ground in punting, and Hay [8] found that ball position relative to the support foot was an important variable in football kicking. The fact that initial ball velocity was not significantly different between the four different instep foot placements in this study may indicate that, a) the instep foot positions alters another factor such as ball trajectory, b) maximal ball velocity is not the best resultant of the effects of altering instep foot positions, and c) the velocity does not alter, but the accuracy of the kick and distances that the ball will travel may vary due to the instep foot positions.

The right knee moment was also expected to be greater in the “next to” instep foot condition, as we expected a greater velocity of the ball in this condition. This was based on previous knowledge where the moment and the velocity of the limb are closely related. However, this was not the case as the ball velocities were not statistically different between the foot placement conditions, and therefore neither were the right knee moments. As seen in the results, the right knee moments did not vary greatly between conditions. The trajectories of each condition were very similar, which could help explain the similarities in the ball velocities. There are some slight variations seen between the conditions at initial contact with the ball, however these are again non-significant and could be due to the subjects focussing on the placement of their foot on the marked instep positions rather than focussing on kicking the ball at maximum velocity.

The right hip angles and right knee angles throughout the kicking movement were also very similar between conditions for each subject, which may also explain the similar ball velocities. At initial ball contact, patterns were present in knee angles where the “in front” condition demonstrated the greatest angles and “wide” and “behind” conditions demonstrated the smallest. This can be explained in kinematic terms, where if you place your foot “in front” you ultimately shift your body forward. This creates less time for the knee to fully extend before contacting the ball. In comparison to the “wide” and “behind” conditions, subjects had enough time to generate the required extended kick.

Some limitations were present in our study that may have affected our findings. These included both procedural and equipment limitations. One of the main limitations was that accuracy demands were not placed on the kicker, and therefore did not simulate a “real” kicking performance. This is because place kicking requires maximal ball velocities whilst maintaining accuracy, whereas our study only focused on maximal ball velocity. Other procedural limitations included the foot placement positions not being individualised to suit the different body sizes of the participants. Also their preferred foot placement was not taken into consideration. The subjects found it difficult to correctly place the instep foot in the required positions and commented that they were focussing on their instep foot placement rather than the kick itself. This added to the already present inter-subject variability in kicking technique. Along with these previously listed limitations are the limited number of trials, limited time, and also the limited number of participants. More participants would be required to test the overall validity and reliability of this study, especially those who are professional place kicking athletes. Another very important limitation was the environment in which the experiment was performed. The study was performed indoors using the Vicon analysis system, because it was the only three dimensional analysis system available to us. However it was not an ideal testing environment for rugby place kicking as the ball had to be caught in the net and therefore other factors such as overall ball trajectory and distances could not be measured. Also, being indoors the footwear worn by the participants were their running shoes rather than their rugby boots, as they could not be worn on the testing surface. Another possible limiting factor of performing the test indoors is a psychological factor as the subjects are not used to this laboratory environment and therefore this may also affect their performance.

There were fewer equipment limitations that could have affected our results, such as vibration of the markers as some were attached to the subjects clothing. Also in the data analysis a few errors were present, in that some of the marker points on the subject and the ball disappeared during analysis. To overcome this we had to approximate the unknown coordinates by using BodyBuilder software to fill in the missing trajectories.

For further research we suggest that an outdoor three dimensional analysis system be used to incorporate a more realistic environment. This would help eliminate limiting factors such as incorrect footwear and psychological issues. This will incorporate the contribution of kicking distance and provide accuracy measures in analysing kicking technique. Accurate kicking measures will be enabled in an outdoor environment as it will allow us to provide subjects with a target to aim at. Therefore a more realistic kicking demand will be placed upon the subject. Further research could include other dependent variables such as ball trajectory, kicking distances, various body postures, individual segment analysis and ground reaction forces. Also as there are many individual differences between kicking techniques, it may be more affective to apply changes to external factors, such as the ball or kicking tee, to investigate whether these alterations can produce more optimal results towards the accuracy of the kick. Lastly, we recommend the analysis of professional and renowned place kickers as they obviously have the best kicking techniques as of yet.

5. Conclusion

Due to the non-statistically significant data obtained, our study concluded that ball velocity is not affected by various instep foot positions. From analysing the data gathered from the Vicon system, we were able to construct graphs which displayed trajectories of the hip angle, knee angle and knee moments involved in kicking. The similarities in the trajectories of the graphs could be an explanation as to why ball velocity was not affected by the various conditions. Limitations existed in our study which include incorrect footwear, indoor laboratory environment setting, marker placements, lack of professional kicking athletes, lack of trials, lack of knowledge of overall testing and experiment processes, and inter-subject variability in kicking technique. Therefore, further study is required to incorporate a more realistic kicking environment and to eliminate possible limiting factors.

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