Comparisons of foot to ball interaction in Australian Football in elite males

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Submitted for the degree of Bachelor of Applied Science (Honours) in Human Movement

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Abstract

Drop punt kicking is considered the most important skill in Australian Football (AF) and impact is the most crucial element in performance. Previous research on impact in AF kicking has used pre and post ball contact data to calculate average foot-ball characteristics but there has been no evaluation of the phase during impact. Important information has been found in soccer performing this analysis and importantly some parameters such as force have been found to be two times average force. The aims of the study were to evaluate foot and ball velocity during impact and compare impact differences between distance and accuracy kicks. Eleven elite AF players were fitted with reflective markers on the kick leg and foot and kicked drop punt kicks with their preferred foot attempting to hit a 20m target (accuracy) and performing maximal distance kicks. Two-dimensional 4000Hz video recorded impact and from this footage, shank, foot and ball markers were tracked using ProAnalyst software. Distance kicks displayed significantly larger foot and ball velocity, contact distance, average and peak force, work and impulse while accuracy kicks exhibited larger contact time and greater plantarflexion at the ankle throughout impact. Foot to ball ratio did not differ between accuracy and distance kicks. The profile of impact was successfully described where many similarities with soccer kicking existed. It was suggested that throughout the deformation phase of impact foot is applying force to the ball while during the reformation phase ball was applying force to the foot. Peak deformation did not occur at the crossover point of foot and ball velocity as seen in soccer kicking. Active changes in ankle angle were exhibited as accuracy kicks displayed a greater range of movement. The results of distance kicking suggested that decreasing ankle rigidity led to increases in performance which is in contrast to previous literature.

STUDENT DECLARATION

I, James Peacock, declare that the Bachelor of Applied Science (Honours) in Human Movement thesis titled *Comparisons of foot to ball interaction in Australian Football in elite males* is no more than 12,000 words in length including quotes and exclusive of tables, figures, appendices, bibliography, references and footnotes. This thesis contains no material that has been submitted previously, in whole or in part, for the award of any other academic degree of diploma. Except where otherwise indicated, this thesis is my own work.

Signature: ……………………………………………………….. Date: ……………………

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Referencing

The referencing style used throughout this thesis is *APA* (6^{th}) system.

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1.0 Introduction

Drop punt kicking is the most important skill in Australian Football (AF) and is used to move the ball efficiently around the field. Kicks are targeted to reach a desired distance and/ or direction to enable players to score maximal points and for team members to mark the ball. The motion of kicking is considered to be sequential where movement starts at the support leg and moves through to the foot of the kicking limb where foot and ball make contact during the swinging phase. After impact ceases the flight path of the ball can no longer be altered which is why impact is considered the most important phase of the kicking motion.

Previous research looking at AF kicking has used pre and post ball contact data where analysis has been limited to calculating average foot-ball characteristics. It is not known what occurs during the impact phase of AF kicking however analysis of rugby league (Ball, Ingleton, Peacock, & Nunome, 2013) and soccer (Shinkai, Nunome, Isokawa, & Ikegami, 2009) kicking throughout foot-ball contact has discovered that important impact characteristics were severely underestimated once compared to average values. A tri-axial motion of the foot has been found to occur in soccer kicking (Shinkai et al., 2009), while other key parameters such as peak force to be approximately two times average force (Ball et al., 2013).

Kicks are targeted to reach a desired distance and/ or direction from its origin. The speed-accuracy trade off states that when the accuracy of a task is increased, the ability to maintain speed decreases and vice-versa. This principle questions whether impact factors differ when either distance or accuracy is amplified. All previous research focusing on impact in AF kicking used a pre/post-ball contact data where comparisons were made between 30m and 50m accuracy kicks (Ball, 2008b), preferred and non-preferred distance kicking (Smith, Ball, & MacMahon, 2009) and junior to senior kicking (Ball, Smith, & MacMahon, 2010). No previous research has specifically compared distance and accuracy kicking.

1.2 Factors influencing impact

It is during impact that the ball changes direction and magnitude of the velocity vector to reach the target which is a specified distance and direction from the kicker. Previous research in AF kicking has found that foot speed prior to impact correlates highly with ball speed after impact ($r = 0.68$) (Ball, 2008a). However, the author reported that other variances for distance kicking existed that were not calculated and suggested that impact or ball flight characteristics could be of importance.

The transfer of energy/ momentum from foot to ball is largely dictated by the velocity of the foot prior to impact however impact factors also influence the nature of impact and have found to differ among kicking types. Correlations between junior ($r = 0.57$) and senior ($r = 0.79$) AF kickers between foot and ball speed have differed where Ball et al., (2010) suggested that impact factors could explain this difference. Impact factors describe the way the foot applies the magnitude and direction of the force vector to the ball throughout the duration of impact. Key factors of impact are ball orientation, position of ball on foot, behaviour of the foot due to impact with the ball and work done on the ball (Ball et al., 2010). This can be simplified into two separate categories: behaviour of the foot and behaviour of the ball.

1.3 Aims

The aims of the present study are;

- Compare impact characteristics of drop punt kicking between accuracy and distance kicking using elite male AF players.
- Describe the profile of impact in elite male AF drop punt kicking.

2.0 Literature review

2.1 Behaviour of the foot throughout impact

Foot and ball velocity

Previous research on impact in AF kicking has found differences in foot and ball velocity between specific kicking types. Ball (2008b) reported significant differences in change in ball velocity between 30m (22.1m/s) and 50m (25.0m/s) accuracy kicks in elite AF players. Smith et al., (2009) reported significant differences in foot (26.5m/s to 22.6m/s) and ball (32.6m/s to 27.0m/s) velocity for maximal distance kicks between preferred and non-preferred kicking limbs, respectively. Significant differences in maximal distance kicks between senior (26.5m/s and 32.6m/s) and junior (21.3m/s and 24.7m/s) kickers were reported in foot and ball velocity, respectively (Ball et al., 2010).

Velocity of the foot and ball throughout the duration of impact has been previously documented in rugby league and soccer kicking (Ball et al., 2013; Shinkai et al., 2009; Tsaousidis & Zatsiorsky, 1996). Shinkai et al., (2009) split impact into four separate phases and suggested that approximately three fourths of impact duration was required to accelerate the ball. Throughout phase 1, deformation of the ball mostly occurred as the centre of gravity of the ball accelerated. Phase 2 saw a rapid acceleration of the ball and deceleration of the foot and lasted until foot and ball velocity were equal in magnitude where peak deformation of the ball occurred. Phase 3 is the beginning of the reformation phase of impact where the velocity of the ball continued to accelerate. As the acceleration and deceleration of the foot and ball plateaued, phase 4 begins and lasted until ball release.

Change in ankle angle

It has been hypothesized that foot motion throughout impact is most likely associated with the relative contact point along the foot (Shinkai et al., 2009). Using three-dimensional high speed video recording at 5000Hz, it was reported the foot underwent a tri-axial motion that included plantar/dorsal-flexing, abduction/ adduction and inversion/ eversion movements. It was hypothesised that the corresponding movements of the ankle were a result of the force vector applied to a relative point about the centre of gravity of the foot. This association was identified after the foot exhibited abduction and eversion throughout the duration of impact where it was suggested that the force vector transferred diagonally through the medial side of the foot. The results of Tol, Slim, van Soest, & van Dijk, (2002) reported the anteromedial side of the foot was most frequently used as the point of contact in instep kicking and was used as supporting evidence by Shinkai et al., (2009). As a result, it was hypothesised that contact occurring on the proximal side of the centre of gravity of the foot (CGF), dorsal-flexing motion occurs. Impact applied on the distal side of the CGF generates plantar-flexing motion. The profile of ankle motion throughout impact in soccer kicking displayed dorsi-flexing movement until approximately one fourth of impact before plantar-flexing movements occurred where it was suggested that as deformation increased, the point of contact moved distally across the CGF (Shinkai et al., 2009).

It is believed that improving the rigidity of the kicking limb in impact is beneficial for performance as a means of increasing effective mass. Using the conservation of momentum which is proven to be a method of only approximating impact characteristics, Shinkai, Nunome, Suito, Inoue, & Ikegami, (2013) reported the mass of shod foot to be approximately 84.0 ± 9.6% of the effective striking mass indicating that the momentum of the kicking limb does not include solely the foot, but part of the shank as well. Previous research focusing on impact in AF kicking has reported the foot to plantar-flex throughout the duration of impact where significant differences were reported between senior and junior kickers (Ball et al., 2010). It was reported that senior kickers plantar-flexed 4° while junior kickers plantar-flexed 6° and the author suggested differences between senior and junior kickers were due to lower strength and suggested that improvements of strength might lead to improved performance in distance kicks. Similar findings have been reported in soccer kicking (Asami & Nolte, 1983; Sterzing & Hennig, 2008) however this was questioned after (Nunome, Lake, Georgakis, & Stergioulas, 2006) reported that one participant who displayed the largest foot velocity also produced the greatest change in ankle angle.

2.2 Nature of the ball throughout impact

Work

Significant differences in work have been reported in studies focusing on impact in AF kicking. Ball, (2008b) compared 50m (271J) to 30m (198J) accuracy kicks where a significant-medium effect (d = 1.15) was found. Comparisons between preferred (225J) and non-preferred (156J) distance kicks differed significantly with large effect (d = 1.53) (Smith et al., 2009). Ball et al., (2010) reported significant differences existed between senior (225J) and junior (136J) with a large effect (d = 2.5) for distance kicking.

Contact distance and contact time

Significant differences have been reported in studies focusing on impact in AF kicking in contact distance and unclear results exist for contact time. Contact distance differed significantly between 50m (0.24m) and 30m (0.19m) accuracy kicks with a small effect size (d = 0.046) where it was also reported contact time did not differ significantly (50m = 10.0ms, 30m = 9.8ms) (Ball, 2008b). Comparisons between preferred and non-preferred distance kicking exhibited significant differences in contact distance that were large in effect (d = 1.50) with preferred kicking limbs producing 0.22m and non-preferred 0.19m (Smith et al., 2009). Contact time (preferred = 11.53ms, non-preferred = 12.05ms) differed insignificantly after Bonferroni adjustment, with a medium effect (d = 0.37). Ball et al., (2010) reported significant differences in contact distance comparing distance kicking data from Smith et al., (2009) to junior kickers (senior = 0.22m, junior = 0.20m) with a large effect size (d = 1.0). A small non-significant effect was reported between senior (11.06ms) and junior (11.53ms) in contact time.

Force and deformation

Previous studies focusing on impact in instep soccer kicking reported that peak force could be estimated assuming the force curve throughout impact is of a half-sine wave (Tol et al., 2002). To estimate peak force, the authors multiplied average force (1025N) by π/2 which equated to 1710N. However, this method has assumed that peak force occurs at the midpoint of impact. Force and deformation are linked in that deformation increases as the force per cross sectional area applied to the ball increases. Other studies focusing on impact have found peak deformation to occur prior to the midpoint of impact (Shinkai et al., 2009; Tsaousidis & Zatsiorsky, 1996). Shinkai et al., (2009) reported peak force to be greater than two-times average force and while it was not measured, suggested that peak force occurred at the point of maximal deformation. This indicates that the force curve in soccer kicking is not of a half-sine wave however, peak force is likely to occur at the point of maximal deformation.

Classical impact (conservation of momentum)

Impact between foot and ball was thought to be described by the classical impact theory however research has found that muscles provide work throughout the duration of impact. The conservation of momentum was used to estimate the effective mass in junior to senior soccer kicking and calculate differences between soccer and American football (Plagenhoef, 1971; Shinkai et al., 2013). However, classical impact theories incorporate assumptions that are not entirely representative of the true nature of the mechanics involved in the impact. Tsaousidis & Zatsiorsky, (1996) argued the conservation of momentum was inadequate to calculate impact characteristics due to muscle work completed during impact. Therefore, foot to ball impact characteristics derived from classical impact theory should be considered as estimates, rather than accurate details.

Foot to ball speed ratio

Foot-to-ball speed ratio has been suggested to be a valid measurement of ball impact efficiency. Research focusing on the maturation process of soccer kicking from junior to senior via cross-sectional method stated that foot-to-ball speed ratio is a measure of impact efficiency (Shinkai et al., 2013). Foot-to-ball speed ratio has been used to distinguish impact differences between kicking groups in AF. Comparing senior to junior kickers, Ball et al., (2010) recorded average impact characteristics via pre/ post-impact data collection at 6000Hz in two-dimensions. The author reported a non-significant medium effect between senior (1.23) and junior (1.16) kickers for distance kicking. Comparisons between preferred (1.23) and non-preferred (1.20) distance kicking limbs using the same methods produced a medium effect that was non-significant (Smith et al., 2009).

3.0 Methods

3.1 Participants

Thirteen participants who were currently playing in, or had recently (within the last 2 years) retired from AFL level participated in this study (average age = 26.8 years old, SD = 6.8). Of the recent retirees, all were still currently involved in training and playing games at club level. Prior to starting, participants completed informed consent forms that were approved by the University Human Research Ethics Committee (VUHREC). Participants wore shorts and football boots they frequently used in games/ training.

3.2 Laboratory

Two systems were used to capture the kinematic data; two-dimensional high speed video (HSV) and three-dimensional (3-d) motion capture (VICON). A kicking area was marked on the floor to aid in the reliability of the athlete kicking in a capture volume for optimal measurement accuracy. The HSV camera captured the foot-to-ball impact kinematics with a sampling rate of 4000Hz. The 3-d motion capture volume was optimised to include toe off of the kicking swing phase and heel contact of the follow through phase. Positioned 20m to the front of the kicking area was a kicking target that simulated kicking toward a player (Figure 3.1).

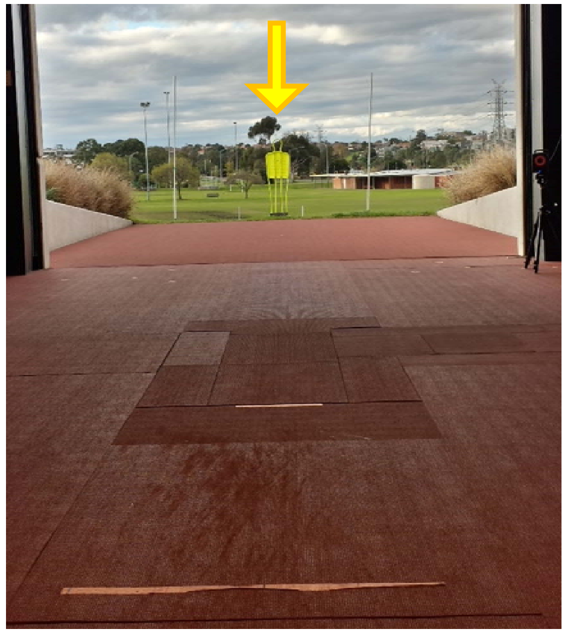

Figure 3.1. Vision of the target 20m away from the kicking area.

The HSV camera that was used for the study was a Photron Fastcam SA3 (Photron, San Diego, CA, USA, Inc.). Two-dimensional kinematic data was recorded in the sagittal plane (i.e. camera positioned lateral to the kicking leg). From this data, foot and ball impact characteristics were calculated. A calibration frame was used to reconstruct the kicking area into 2-d metric coordinates. Three calibration files were used to accommodate for the player kicking at different depths in the camera field of view to reduce out of plane errors. Similar to past studies looking at impact characteristics in AF kicking, ball contact was visually identified (Ball, 2008; Smith, Ball, & MacMahon, 2009). Recording data at 4000Hz typically captures approximately 40 data points during the impact phase of the kick. This data provided the input variables for deriving the force and velocity profiles throughout this impact phase. These profiles were then compared to previous studies (Ball, 2008; Nunome, Lake, Georgakis, & Stergioulas, 2006; Shinkai, Nunome, Isokawa, & Ikegami, 2009; Smith et al., 2009).

The kicking volume was reconstructed into three-dimensional space from ten VICON T-40s cameras (Oxford Metrics Group Plc [OMG], Oxford, UK) with a sampling frequency of 500Hz. The cameras were positioned around the kicking area, run up area and follow through area. The 3-d motion capture system was used to calculate the geometric centre of ball at the instant of ball contact (see methods section 3.4).

Four half dome markers were attached on the ball, where three markers faced towards the lateral side of the kicking limb, and the single marker on the opposing side (Figure 3.2). A Sherrin 'Match Ball' (Russell Corporation Australia, Scoresby, Australia) was used for testing as this ball is currently used in the AFL. Due to impact characteristics of AF Kicking, markers can be forced to detach from the ball. Therefore, prior to being placed on balls, the marker positions were carefully measured, marked with permanent ink and attached securely. In the case where a marker was forced to detach during a kick, it could be re-placed in the same position. Marker positions were designed where the average coordinates (X and Y) of the three lateral side markers represents the centre of the ball in two dimensional data. The three-dimensional motion capture system can calculate the geometric centre of the ball based on static captures.

Figure 3.2. Half dome reflective markers placed on the balls.

Reflective markers (14mm, B&L Engineering, Santa Ana, USA) were secured to body landmarks on the preferred kicking limb. Key limbs were the shank and foot (Figure 3.3). A cluster of three markers attached to a rigid body were placed on the midpoint of the shank following the tibia. Three individual markers were placed on the foot where the average of the three markers represent the centre of the foot. Individual locations of markers placed on the foot were the posterior calcaneus, head of the 5th metatarsal and base of the 5th metatarsal.

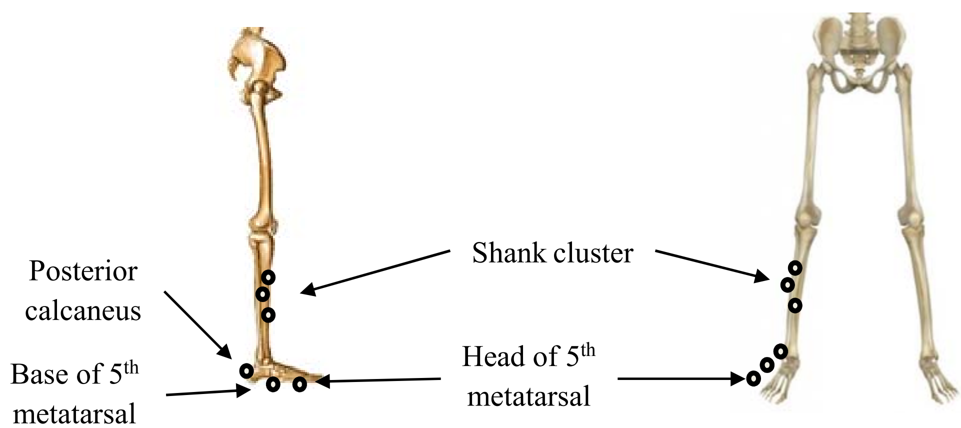

Figure 3.3. Location of reflective markers on the kicking limb in the sagittal plane (left image) and in the frontal plane (right image). The majority of markers are placed on the preferred kicking limb.

3.3 Task

Participants completed a standardised warm-up that included jogging, flexibility exercises (e.g. dynamic stretching) and kicking. Following warm-up participants completed a familiarisation of the testing area by completing a minimum of 10 kicks prior to the commencement of testing.

There were two kicking conditions prescribed. Players completed two trials under each kicking condition;

Condition 1: Accuracy kick

For accuracy kicks, an adaptation of the 'Buckley kicking test' was used. The 'Buckley kicking test' has been used at draft camps for the AFL and is a tool used to assess the ability of kicking skill. The adaptation of the 'Buckley kicking test' involved participants completing only the 20m kick with the preferred leg from the test. Participants started by facing the opposing direction of the target, they were required to run toward a cone 2m away from the kicking target, turn 180 degrees and then run 3m towards the kicking target and kick.

Condition 2: Maximal distance kick

Participants kicked the ball maximally with a self-selected approach angle and speed.

3.4 Geometric centre of ball

A unique algorithm was used to combine 3-d with HSV data to calculate the geometric centre of the ball throughout the duration of impact. Previous studies focusing on the impact phase of kicking estimated the true nature of ball throughout the duration of impact by two methods: i) tracking the edge of the ball from which the geometric centre of the ball can be calculated (Tsaousidis & Zatsiorsky, 1996), or ii) using algorithms to incorporate the amount of deformation to estimate the centre of gravity of the ball (Shinkai et al., 2009). In the present study, the 3-d motion capture system calculated the geometric centre of ball (GCB) using all four markers on the ball, where the 2-d HSV system estimates the GCB using the three markers on the lateral side of the ball. However, due to the nature of AF kicking the ball is dropped from the participants' hand before foot-to-ball contact where the ball can rotate slightly about its longitudinal axis. When this occurred, the estimated ball centre derived from the 2-d sagittal plane coordinates of the three ball markers did not accurately represent the GCB (Figure 3.4). To overcome this, a relationship combining the 3-d ball-marker position with the HSV data was used. This enabled the position of the GCB to be given in the coordinate system of the HSV data (i.e. relative to the physical ball markers in the HSV data) and to allow for the GCB to be calculated throughout the duration of impact. The true nature of the GCB was accurately measured from HSV data where all ball parameters were derived.

Figure 3.4. Example images showing slight rotation of the ball about it's longitudinal axis. The ball on the left has slightly rotated outwards compared to the ball on the right. During ball 'twist', the average of three markers does not represent the geometric centre of the ball. This could lead to an over or underestimation of the true nature of the ball during impact.

A three-step process was required to calculate the GCB coordinates within the HSV data that involved creating a relationship with the 3-d motion capture data and transferring it to the HSV data.

1. Firstly, at the instance before ball contact the GCB was represented as a 3-d 'virtual marker' that was derived from the 3-d coordinates of the four 'tracking markers' attached to the ball.
2. Secondly, using these five coordinates two relationships (to generate X and Y values) (equations 3.3.1 and 3.3.2) that included two physical markers (that were used in both 3-d and HSV systems) and the virtual GCB marker were made.

   $$GCB_x = P3_x \pm h\left(BM1_y - BM2_y\right)/d \qquad (3.3.1)$$

   $$GCB_y = P3_y \pm h(BM1_x - BM2_x)/d \qquad (3.3.2)$$

   This was possible by using the 'intersection of two circles' (Bourke, 1997) (Figure 3.5). The relationships included multiple fixed-distance variables (equations 3.3.3-3.3.8) that were calculated within the 3-d data.

   $$P_3 = BM_2 + a(BM_1 - BM_2)/d \qquad (3.3.3)$$

$$a = (r_1{}^2 + r_2{}^2 + d^2)/(2 * d) \tag{3.3.4}$$

$$d = Distance_{between\ BM1\ and\ BM2} \tag{3.3.5}$$

$$r_1 = Distance_{between\ GCB\ and\ BM2} \tag{3.3.6}$$

$$r_2 = Distance_{between\ GCB\ and\ BM1} \tag{3.3.7}$$

$$h = \sqrt{r_1{}^2 - a^2} \tag{3.3.8}$$

The ‘intersection of two circles’ originated from geometry where they were used to calculate the intersection of two overlapping circles. Circles that overlap have two intersections, where the ‘±’ sign was used to distinguish between each intersection. As a result, the relationships generated in the present study were double-checked within the 3-d data to ensure that the correct intersection was used.

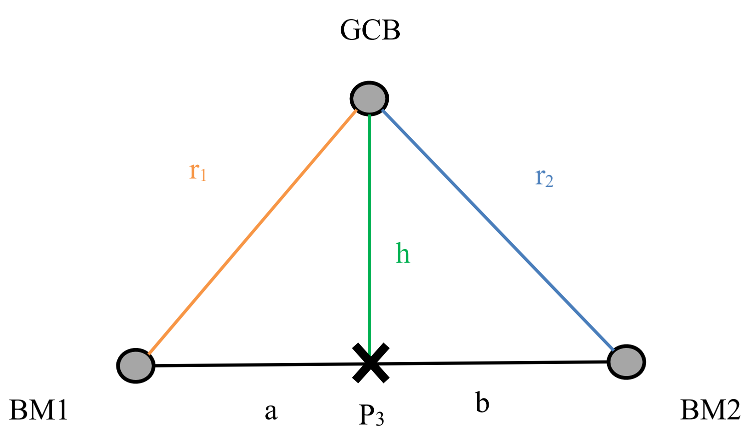

Figure 3.5. The position of GCB can be calculated from two known points. The position of ball marker 1 (BM1) and ball marker 2 (BM2) were used as reference points to the GCB.

3. Thirdly, the two relationships were applied to the respective markers in the HSV data where the GCB was calculated in the HSV coordinate system.

This process was repeated three times, to ensure all three reflective markers HSV were utilised evenly when calculating ball parameters. This process of generating six relationships in total (2 coordinates x 3 different relationships) reduced the total amount of maximal error by one-third by averaging the relationships. Figure 3.6 represents a visual interpretation of the design of the three relationships.

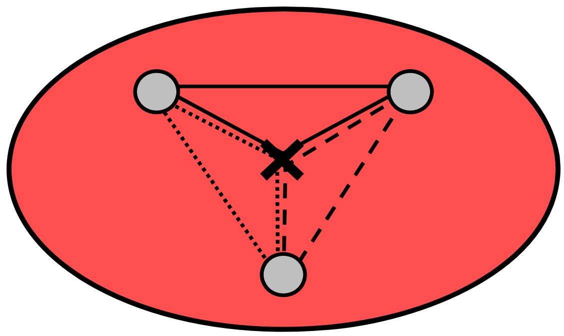

Figure 3.6. Three separate relationships were used to reduce errors. The X on the image represents the GCB. Relationship A (solid line) included markers B1 and B2, relationship B (dotted line) included markers B1 and B3, relationship C (dashed line) included markers B2 and B3.

3.5 Analysis

All reflective markers collected from HSV were digitised into 2-d position coordinates using ProAnalyst software (Xcitex Inc., Cambridge, Massachusetts, USA). Each video trial was cut into smaller time periods from 5 frames (i.e. 5 x 4000Hz) prior to ball contact to 5 frames after contact. This time period was selected because it enabled an appropriate method to standardise the smoothing process. After all reflective markers were transposed into 2-d coordinates, the data was exported into Visual3D biomechanical analysis software (C-Motion, Inc., Germantown, USA).

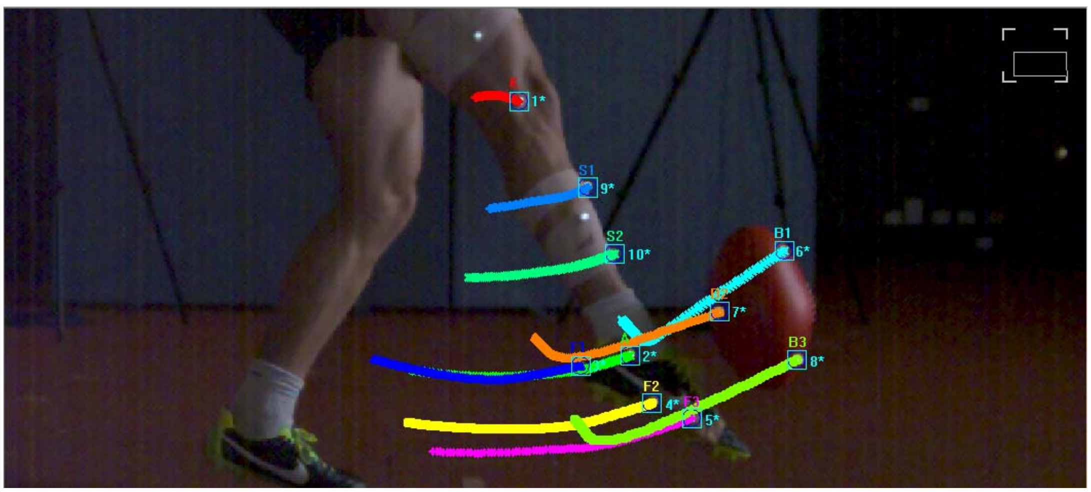

Figure 3.6. Tracking of reflective markers with software Proanalyst from the two-dimensional data.

Visual3D software was used to process and analyse data:

1. Data Processing (Smoothing/Filtering)

2-d data from HSV were smoothed using a Butterworth digital filter, with a cut-off frequency of 280Hz. The decision of the cut-off frequency was based on four criteria: 1) residual analysis (Winter, 2009; Yu, Gabriel, Noble, & An, 1999); 2) the change in parameter values using different cut-off's; 3) a visual inspection of data transformation; and 4) previous literature (Nunome et al., 2006; Shinkai et al., 2009). Residual analysis found that an optimal range was between 170-260Hz. The influence of different cutoff frequencies on chosen parameters derived an optimal range between 240-280Hz. Visual inspection showed that noise was evident when selected cut-off frequencies were below 240, and for frequencies above 300Hz important features of the true signal was being removed. Previous literature has used a range of 200-350Hz. Further details on the rationale behind the selection of the cut-off frequency can be found in appendix B.

2. Parameterisation (Data Analysis):

Processed (filtered) data was used for obtaining variables associated with foot and ball impact characteristics (Table 3.1).

Table 3.1. Parameters of foot and ball impact characteristics

Measurement	Formula
Contact time	The time between ball contact and ball release $(time_{ball\ release} - time_{ball\ contact})$
Contact distance	Displacement of the ball between ball contact and ball release $position\ ball_{release} - position\ ball_{contact}$
Velocity (m/s)	$v = \frac{d}{t}$
Foot velocity* $(\boldsymbol{v_f}, \boldsymbol{m/s})$	Average foot velocity over 5 frames before impact
Ball velocity* $(\boldsymbol{v_b}, \boldsymbol{m/s})$	Average ball velocity over 5 frames after impact
Foot-to-ball speed ratio	$Foot\ to\ ball\ speed\ ratio = \frac{v_b}{v_f}$
Acceleration (a)	$a = \frac{v}{t}$
Force (N)	Force applied to the ball (reaction force of the ball) (m = 0.45kg) $F = m.a$
Average force (N)	The average force throughout ball contact
Peak force (N)	The maximal amount of force during ball contact
Work (J)	The total amount of work applied to the ball during ball contact $W = F.d$
Ankle angle (°)	Ankle angle is calculated where ankle angle at ball contact = 0°. Values > 0° = plantar flexion $ankle\ angle = (Shank\ angle + Foot\ angle)$
Change in ankle angle	The difference in ankle angle from ball contact to ball release.

*using five frames before and after ball contact to calculate velocity reduces the maximal amount of error.

3.6 Statistical analysis

The parameters derived from distance and accuracy kicks were exported to Microsoft Excel (Microsoft Corporation, Redmond, WA, USA) where a three-step statistical analysis was conducted.

1. **Independent and dependent variables**

   Independent variables: accuracy and distance kicks.

   Dependent variables: there are two types of dependent variables; discrete and continuous variables. Discrete variables that are a singular value and continuous variables that are plotted against time throughout the duration of impact.

   Discrete variables: contact time, contact distance, foot velocity, ball velocity, foot to ball speed ratio, change in ankle angle, force (peak), force (average), work and impulse.

   Continuous variables: Foot velocity, ball velocity, force and change in ankle angle.

2. **Hypotheses**

   Aim 1: to compare impact characteristics between distance and accuracy kicks

   Null – hypothesis: No significant differences existed between accuracy and distance kicks

   Alternative hypothesis: Significant difference existed between accuracy and distance kicks

   Aim 2: to describe the profile of impact in AF kicking

3. **Statistical design**

   Aim 1:

   Discrete variables: repeated-measures t-tests with a significance level of 0.05 were performed using 1-tail tests. The choice of 1-tail tests were based on comparisons between 30m and 50m accuracy kicks where statistically significant values were found in contact distance, change in ball velocity and work (Ball, 2008). The current study was expected to generate larger differences between the kicking conditions due to a greater difference in kick distance (20m and maximal kicks which are estimated to be approximately 60-70m). Therefore based on this prior data, the choice of 1-tailed is considered more appropriate (df = 10, $p < 0.05$, effect size (d) = large > 0.8, medium > 0.5 and small > 0.2, Cohen, (1988)).

Continuous variables: All trials were normalised from 0 – 100% of ball contact to remove the influence of inter-trial and inter-subject differences in contact time. Data were split into four phases of impact following the criteria of previous impact analysis of soccer kicking (Shinkai et al., 2009) to allow statistical analysis to be conducted in each phase. Null-hypothesis testing was completing by graphing 1-tailed 95% confidence intervals (Welkowitz, Cohen, & Lea, 2012) (see appendix C).

Aim 2:

Using distance kicks, the profile of impact (foot velocity, force and ball velocity) was qualitatively and quantitatively described where no statistical analysis was conducted as only 1 independent variable existed.

4.0 Results

4.1 The profile of impact

Accuracy and distance kicks displayed similar impact profiles and were split into four different phases to ease running statistical comparisons. The impact profile of distance kicks (figure 4.1) will be qualitatively described. Four phases of the foot-to-ball impact phase was determined based upon several key events: phase 1 was defined when foot and ball make contact; phase 2 begins with the increase in ball velocity; phase 3 begins when foot and ball velocity were equal; phase 4 begins when foot and ball velocity start to plateau. This is the final phase of contact that runs until foot and ball contact ceases.

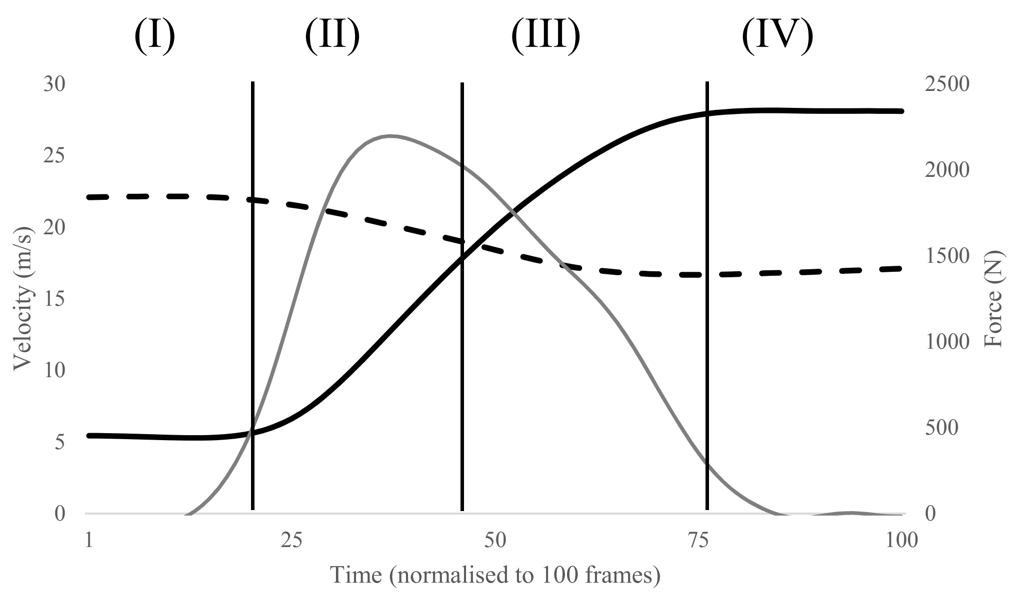

Figure 4.1. Ball velocity (solid black line), foot velocity (dashed black line) and force (grey line, secondary axis) of distance kicks.

During phase 1 of impact, ball and foot make contact where velocity of the foot decreases and velocity of the ball increases due to force applied to the ball. Throughout phase 1 visual inspection showed the ball was mostly deforming. In phase 2 ball velocity rises at a uniform rate and is preceded by the rise in ball reaction force which reaches a maximum peak force prior to the end of phase 2. Phase 3 begins as foot and ball velocity are equal. As this phase proceeds, the force reduces and there is a decline in the positive acceleration of the ball. As ball reaction forces continue to decline, the velocity of the foot and ball begin to plateau. This marks the beginning of phase 4. Throughout phase 4 the velocity of the foot and ball remain constant as the ball travels away from the foot.

4.2 Comparisons between distance and accuracy kicks

Table 4.1 indicates the results of chosen biomechanical parameters of the impact phase, including statistical analysis. Almost all biomechanical parameters showed statistical significance when comparing between distance and accuracy kicks. Distance kicks were characterised by significantly larger contact distances, foot and ball speeds (both before and after ball contact), ball reaction forces, work and impulse compared to accuracy kicks. Conversely, accuracy kicks were characterised by significantly larger contact times and change in ankle angle during impact. Effect sizes were high for significant relationships. While distance kicks produced a larger foot to ball speed ratio with a small effect, this was not significant.

Table 4.1. Results of chosen parameters between accuracy and distance kicks along with statistical analysis.

	Accuracy		Distance		*t-test (P-value)*	*Effect size (d)*	
	Mean	SD	Mean	SD			
Contact time (ms)	13.2	1.4	12.1	1.3	0.005	0.809	Large
Contact Distance (cm)	20.3	2.4	22.8	2.9	0.012	0.855	Large
Initial ball speed (m/s)	4.6	0.2	5.4	0.4	<0.001	1.640	Large
Initial foot speed (m/s)	17.7	0.9	22.1	1.6	<0.001	1.687	Large
Post ball speed (m/s)	22.1	1.1	28.1	2.5	<0.001	1.669	Large
Post foot speed (m/s)	14.4	0.7	17.1	1.6	<0.001	1.479	Large
Foot to ball speed ratio	1.25	0.04	1.28	0.06	0.085	0.471	Small
Peak ball force (N)	1603	114	2286	232	<0.001	1.740	Large
Average ball force (N)	588	64	834	107	<0.001	1.616	Large
Change in ankle angle (°)	7.2	6.4	2.2	3.3	0.011	0.899	Large
Work (J)	119	12	190	31	<0.001	1.657	Large
Impulse (N.s)	7.70	0.43	9.99	1.01	<0.001	1.639	Large

Effect size: d < 0.2 = none, d < 0.5 = small, d < 0.8 = medium and d > 0.8 = large

Figure 4.2 represents the velocity of the foot for distance and accuracy kicks. A statistically significant difference occurred during the entire duration of impact with distance kicks producing higher velocities.

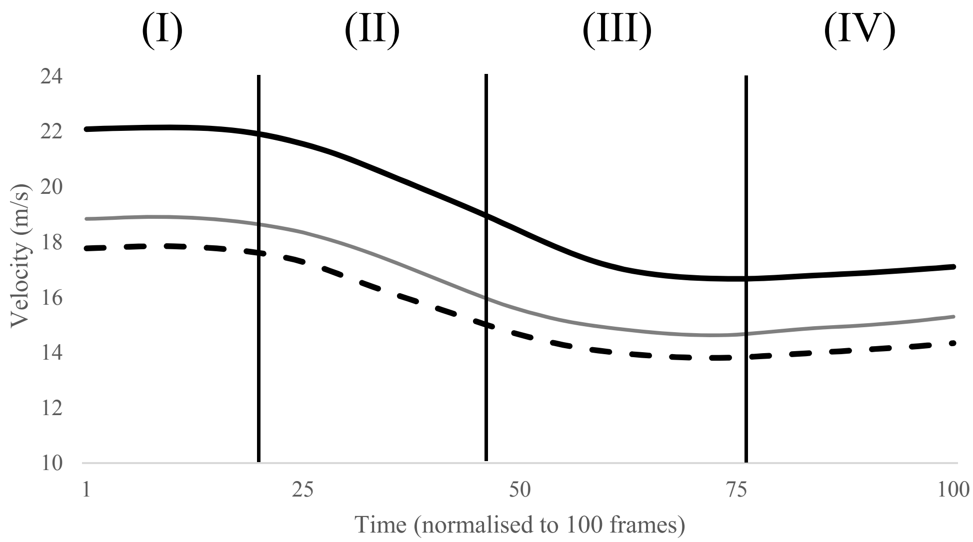

Figure 4.2. Foot velocity. Foot velocity of distance (solid black line) and accuracy kicks (dashed line). 95% confidence intervals (solid grey line) represent a significant statistical difference when the distance kick exceeds this value.

Figure 4.3 represents the change in ankle angle throughout ball contact. Similar patterns were exhibited (dorsi-flexing then plantar-flexing) however magnitude and timing differed between kicking types. A significant difference occurred immediately as distance kicks displayed initial dorsi-flexing motion and at 53% of contact duration the ankle moved into a state of plantarflexion relative to ankle angle at ball contact. Accuracy kicks were in a phase of dorsiflexion for 23% of impact before entering plantarflexion until contact ceased.

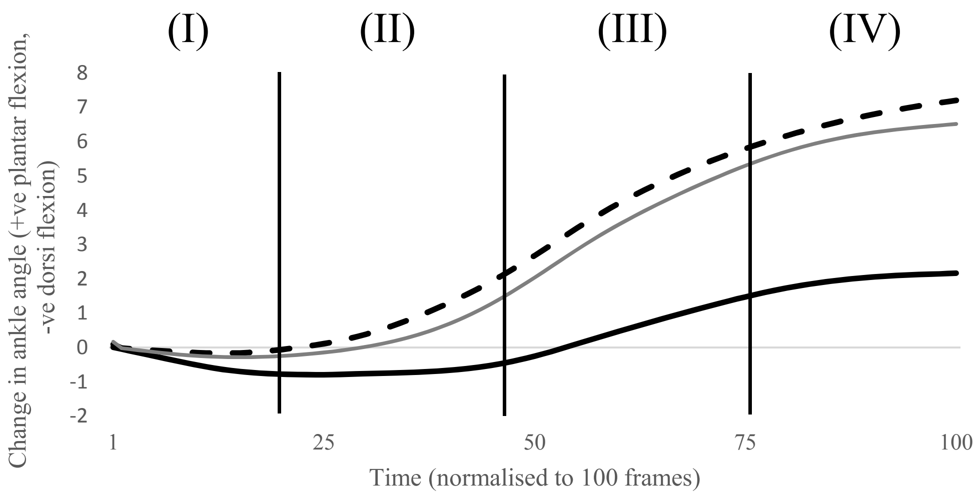

Figure 4.3. Change in ankle angle. Distance (solid black line) and accuracy (dashed black line) represent the change in ankle angle. Positive values represent plantar flexion while negative values represent dorsi flexion. 95% confidence intervals (grey line) represent a significant statistical difference.

Figure 4.4 shows ball reaction force throughout. Throughout phases 2 and 3 a significant difference occurred with distance kicks producing high force values. Peak force occurred midway through phase 2 for both accuracy and distance kicks. Visual inspection of the curves showed no difference in the shape between accuracy and distance kicks where the magnitude was scaled up.

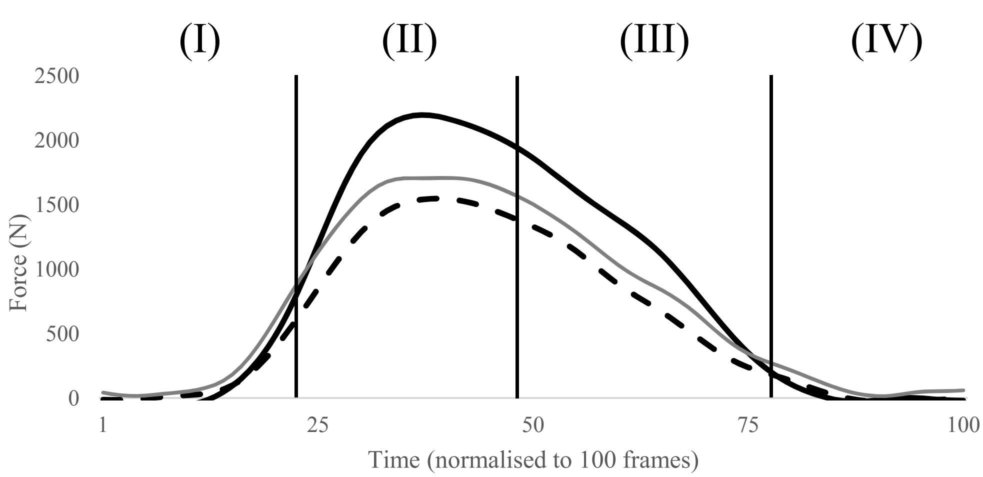

Figure 4.4. Ball reaction force between distance kicks (solid line) and accuracy kicks dashed line). There is a significant statistical difference between the two when the distance kick data exceeds the 95% confident interval (grey line).

Figure 4.5 represents the velocity of the ball throughout impact. Velocity for distance and accuracy kicks increased throughout phases 2 and 3 of impact. Midway through phase 2 through to the remainder of impact a significant difference occurred with distance kicks producing larger values then accuracy kicks.

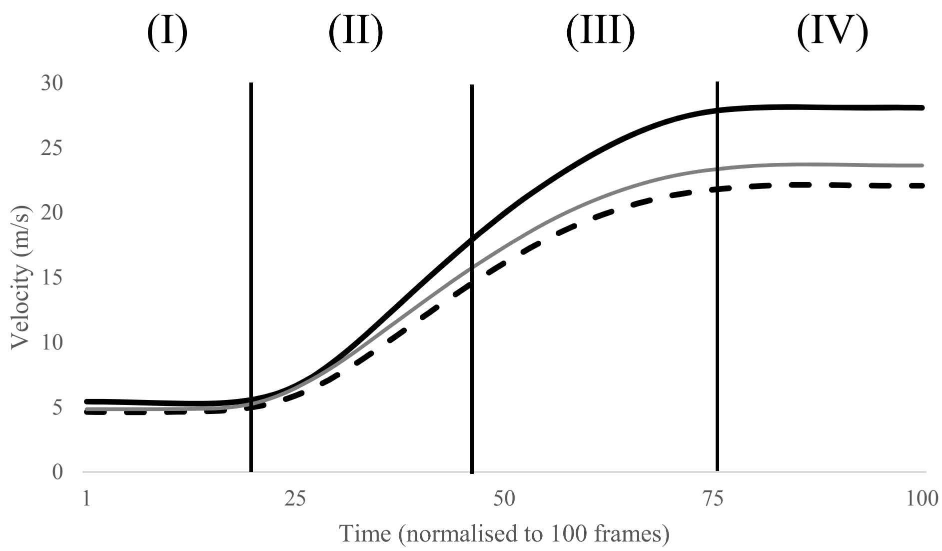

Figure 4.5. Ball velocity. Distance (solid black line) and accuracy kicks (dashed black line). 95% confidence interval (grey line) is achieved when the solid black line exceeds this value and a significant statistical difference occurs.

5.0 Discussion

5.1 Comparisons with previous literature

Comparisons with previous literature show values recorded for the present study are mostly similar. Table 5.1 summarises the previous literature with the current study on chosen parameters. Contact distance, foot speed, ball speed, foot to ball speed ratio, change in ankle angle and peak force all lay within a range of previous data that has focused on ball impact characteristics or kinematic analysis of AF, rugby league and soccer kicking.

Contact time is slightly larger than previous AF literature but lays within a range reported for soccer kicking. The present study reported values of 12.1ms for distance and 13.2ms for accuracy kicks that were larger than the previous 9.8 - 11.53ms reported for AF (Ball, 2008b; Ball, Smith, & MacMahon, 2010; Smith, Ball, & MacMahon, 2009) and 7.2 - 10.9ms for rugby league (Ball, 2010; Ball, Ingleton, Peacock, & Nunome, 2013). The present study did lye within the range of 9-16ms for soccer kicking (Asai, Carré, Akatsuka, & Haake, 2002; Shinkai, Nunome, Isokawa, & Ikegami, 2009; Tol, Slim, van Soest, & van Dijk, 2002; Tsaousidis & Zatsiorsky, 1996).

Results of distance kicking in the present study compared to previous AF research appear to produce lower work, impulse and average force. However, foot and ball speed were in an acceptable range that included data before and after impact indicating the nature of impact is accurate. Work in the current study was lower than the values reported for AF (Ball, 2008b; Smith et al., 2009) and rugby league (Ball, 2010), but was higher than the reported values for junior kickers in AF (Ball et al., 2010) and soccer kicking (Tsaousidis & Zatsiorsky, 1996). Average ball reaction force is slightly lower for distance kicks and substantially lower for accuracy kicks compared to the previous data reported for rugby league (Ball et al., 2013)) and soccer kicking (Shinkai et al., 2009; Tol et al., 2002; Tsaousidis & Zatsiorsky, 1996). Impulse for distance and accuracy is slightly lower than the previous values in soccer kicking that involved amateur participants completing penalty kicks using the instep style of kick (Asai et al., 2002; Tol et al., 2002). While the difference between distance kicks in the present study to the previous literature is approximately 1Ns, the present study involved elite players compared to amateurs in the previous studies. Elite players are expected to produce significantly larger values. As foot and ball speed are within an acceptable range compared to previous data, the discrepancies found in average force, work and impulse in the present study to past literature were not errors. The differences between distance and accuracy kicks across these parameters exhibited greater values in distance kicks which is in accordance with a logical understanding of biomechanics.

Table 5.1. Summary of previous literature on key parameters between AF, rugby league and soccer kicking. All kicks were completed on preferred limb unless otherwise noted.

	Task	Subjects	Contact time (ms)	Contact distance (cm)	Foot speed (m/s)	Ball speed (m/s)	Foot to ball speed ratio	Change in ankle angle (°)	Force (peak) (N)	Force (avg) (N)	Work (J)	Impulse (Ns)
Present study	Distance	Elite	12.1	22.8	22.1	28.1	1.28	2.2	2286	834	190	9.99
Present study	Accuracy	Elite	13.2	20.3	17.7	22.1	1.25	7.2	1603	588	119	7.70
AF – drop punt kick												
(Ball, 2008b)	50m	Elite	10.0	24						1129*	271	
(Ball, 2008b)	30m	Elite	9.8	19						1042*	198	
(Smith et al., 2009)	Distance	Elite	11.53	22	26.5	32.6	1.23	4		1023*	225	
	Distance (non-pref.)	Elite	12.05	19	22.6	27.0	1.20			822*	156	
(Ball et al., 2010)	Distance	Jnr	11.06	20	21.3	24.7	1.16	6		679*	136	
(Ball, 2011b)	45m	Elite			19.0							
(Ball, 2011a)	45m	Elite			18.8							
(Ball, 2008a)	Distance	Elite			26.4							
Rugby league – drop punt kick												
(Ball, 2010)	45m	Elite	7.2	20	20.0	25.8	1.30			1450*	290	
	Grubber	Elite	8.8	12	11.0	13.7	1.27			567*	68	
(Ball et al., 2013)	Distance	Elite	10.9	18	21.3	27.8	1.31		2062	1045		
Soccer kicking – instep kick (unless otherwise noted)												
(Shinkai et al., 2009)	Distance	Elite	9		20.5	29.3	1.43	7.1	2926	1403		
(Tol et al., 2002)	Penalty	Amateur	10.7			24.6				1025		11.0
(Tsaousidis & Zatsiorsky, 1996)	Toe kick - distance	Amateur	16	26	20	25				1150	130	
(Asai et al., 2002)	Penalty	Amateur	9.12	14.7	23.1	25.4						11.1

* = represents post-hoc calculations by the author of the present study.

5.2 The profile of impact

The profile of impact in AF kicking shows many similarities to previous research in soccer kicking. The closest comparisons could made via ball reaction force and foot and ball velocity to Shinkai et al., (2009) described impact using deformation and foot and ball velocity. The four-phase description of impact in soccer was also applicable for punt kicking in AF (Shinkai et al., 2009). The profile of distance kicks in AF showed many similarities with previous profiles of soccer kicking. The largest difference was initial velocity of the ball where a stationary ball was used in soccer kicking. However, from this point initial impact displayed similar results between AF and soccer kicking with a delay in the face of the ball moving as deformation increased throughout the first phase of impact (Shinkai et al., 2009; Tsaousidis & Zatsiorsky, 1996).

Effective contact time is approximately only three fourths as opposed to the entire duration of contact. The profile of impact in AF kicking shows little interaction in the fourth phase where support is provided for Shinkai et al., (2009) whom stated that the effectual duration to accelerate the ball is approximately three fourths of impact duration. It is during phases 1 and 2 of impact where it can be suggested that the foot is applying force to the ball compared to the ball applying force during phase 3 of impact. Little interaction occurs in the final phase. As suggested by Shinkai et al., (2009), the effectual duration to accelerate the ball was approximately three fourths of visually determined ball contact time where during this period the momentum of the ball increases substantially. It can be suggested that during phases 1 and 2 of impact the velocity vector of the ball changes significantly whereas during phases 3 and 4 acceleration of the ball is lower where little contribution of ball acceleration is provided from the foot. The foot merely acts as a body for the ball to reform against and increase velocity.

Peak deformation of the ball doees not occur at the crossover point of foot and ball velocity. Time of peak force occurred at 41% of contact time and the time of the crossover point of foot and ball velocity occurred at 48% of contact time. Peak deformation has been reported to occur when the magnitude of foot and ball velocity are equal in soccer kicking (Shinkai et al., 2009; Tsaousidis & Zatsiorsky, 1996). It has also been reported that peak deformation and peak force were assumed to occur at the same time (Shinkai et al., 2009). The elastic modulus of a solid object is calculated by stress divided by strain or simply put, when a force is applied to the ball, deformation occurs (Serway, 2012). Kicking of a football (or soccer ball) follows the bulk modulus of elastic bodies where it is the resistance to changes in volume and deformation is related to the force per cross sectional area. Deformation will increase as a result of increased force or an increased area of which the force is applied. It is likely that peak force and deformation occur at the same time and why Shinkai et al., (2009) stated that at peak ball deformation it is supposed that ball reaction force reaches is maximum. Differences between timing of crossover point of foot and ball velocity and peak velocity indicate that the crossover point is not likely to resemble peak deformation in AF kicking. The chance of error explaining this discrepancy between crossover point and peak force is unlikely. The timing of peak force occurs prior to the crossover point of foot and ball velocity where after post-hoc analysis of individual results throughout distance kicks peak force did not occur at this intersection, indicating that ensemble averaging has not introduced potential errors. The potential error in calculating instantaneous force is unlikely to explain this difference as the results of individual trials all display the same pattern of peak force occurring prior to crossover point and there is approximately a difference of 200N in the magnitude of force at the time of its peak and the magnitude at time of crossover. Other forces exist in the impact of foot and ball velocity however these are all included under ball reaction forces. External forces other than that applied by the foot are effectively included given the calculations are based on change in ball velocity but regardless would seem to be too low to be influencing this finding. Force due to gravity is approximately 4.5N (ball mass 0.45kg x 9.81m/s^2) and air resistance at a ball speed of 19m/s approximately 25N (using F = ½ .p.v^2.Cd.A, where p = mass density of air = 1.2, v = ball velocity, Cd = drag coefficient = 0.62, A = cross sectional area with ball assumed to be side on or maximum cross sectional area = 0.147 m^2) (Alam, Subic, & Watkins, 2005). Both external forces are much lower than the overall force of 500-2000 N. The use of the geometric centre rather than centre of gravity of the ball could contribute to this although this might be expected to overestimate the peak force rather than change the timing of it. The shape of the ball might be influencing this relationship with the inconsistent shell shape and likely different properties around the point compared to the belly potentially exhibiting different deformation properties. Future work needs to examine this relationship in more detail and with a model that better approximates the centre of mass of the ball.

Previous research estimating peak force from average force is inapplicable to AF kicking. Estimations of peak ball reaction force was calculated by multiplying average force by half sine wave (π/2) (Tol et al., 2002). This assumes that force throughout impact, throughout the deformation and reformation phase occurs in a mirror fashion. Using an average force of 1025N, estimated peak force was 1610N (Tol et al., 2002). This method involves many assumptions regarding the force and subsequent deformation profile throughout duration of impact. Peak force and the crossover point of foot and ball velocity in the present study occur prior to the midpoint of impact. Previous research tracking the deformation profile throughout the duration of impact has found that peak deformation occurs approximately 1-2ms prior to midway of impact (Shinkai et al., 2009; Tsaousidis & Zatsiorsky, 1996) and that during the final phase of impact little interaction occurred (Shinkai et al., 2009). This indicates that the force profile is likely to be skewed toward the first half of impact. Comparisons between estimated peak force from average force and actual peak force calculated show estimated peak force is severely underestimated. Estimated peak force from average force is 1310N compared to actual peak force is 2286N. There is a possibility that the force profile is of a half-sine wave shape throughout the effective duration of impact (phases 1-3). Post-hoc calculations of average force through phases 1-3 show that this method still underestimates peak force. Average force was 1103N throughout phases 1-3 of impact with an estimated peak force of 1732N that is still substantially lower than actual peak force. This indicates that the force profile does not follow a half-sine wave and should not be used to estimate peak force in AF kicking.

Three general patterns of ankle angle exhibited in distance kicks for the present study have also previously been reported in soccer kicking. Most prior research has looked at the average change in ankle angle over the duration where Shinkai et al., (2009) reported three general patterns of ankle angle movement. The first ankle angle movement pattern displayed a delay before distinctive plantar-flexing. The second ankle angle movement pattern dorsi-flexed in the first stage of impact before also distinctively plantar-flexing. The third ankle angle movement pattern displayed a dorsi-flexing angular velocity throughout the entire duration of impact. As reported by Shinkai et al., (2009), the majority of participants in the present study were included in the first (N = 4) and second (N = 6) ankle angle movement groups, where one was found in the third. Statistical differences between the first and second patterns showed no differences in impact efficiency indicating neither group benefits kicking performance (force, foot-to-ball speed ratio, work).

5.3 Distance and accuracy kicks

5.3.1 The nature of the foot

Foot and ball velocity

Distance kicks were characterised by significantly greater foot and ball velocity compared to accuracy kicks. To produce greater distance, a greater foot speed will in-turn create a larger ball speed which results in the ball being propelled further. No study has compared distance and accuracy kicks, but the association of greater foot and ball speeds with greater kick distance has been found in both AF and rugby league kicking (Ball, 2010; Ball, Smith, & MacMahon, 2010). Strong correlations between foot velocity and kicking distance for both senior ($r = 0.79$) and junior ($r = 0.57$) AF kickers have been reported, indicating that as foot speed increases, ball speed increases (Ball et al., 2010). This pattern was also evident in rugby league kicking in comparing ball velocity of the shorter (10-20m) grubber kick to the 45m kick. Statistical analysis by present researcher shows velocity of the ball for the grubber kick (13.7m/s) to be significantly lower than the 45m kick (25.8m/s) ($t(11) = 6.7092$, $p < 0.05$). Comparing 30m to 50m accuracy kicks, Ball, (2008) did not report on foot or ball velocity but stated a significant difference in change in ball velocity with a medium effect.

Two possible explanations for this reduction in foot velocity for the accuracy kicks are the differences of kicking distance and the constraint of accuracy. For the accuracy kick, the target was 20 m away while maximum distance kicks travelled approximately 60m. Examining this in terms of the impulse-momentum relationship, the velocity of the foot is a key determinant of how much momentum is transferred onto the ball. As the distance to the accuracy target was approximately one-third of distance kicks, approximately one-third of the momentum of the ball is required to reach the target if the trajectory remains constant. However results showed that foot speed for accuracy kicks were 80% of distance kicks. This indicated that participants kicked the ball at a much higher velocity than was required to achieve the necessary distance. Two advantages for increased ball velocity are to reduce flight time and to increase relative target area. Players may have been in 'game-mode' where flight time must be minimised to avoid passes being intercepted. Players also increased ball velocity to increase the relative target area. Post-hoc analysis of ball trajectory shows that accuracy kicks departed at an angle of 15° (SD = 2°) and distance kicks 30° (SD = 2°) ($p < 0.05$). Faster ball speeds translate to a flatter trajectory of the ball to reach the same distance where a larger relative target area would exist compared to kicks that exhibited a greater loft. Regardless, the issue of distance alone does not explain the difference in foot and ball speeds so the more likely reason is due to the constraint of accuracy. The speed-accuracy trade off states where accuracy is increased, the speed at which the task can be completed successfully will decrease and vice-versa (Magill & Anderson, 2007). Based upon this theory, it could be expected that players in this study are likely to have slowed foot velocity (and in-turn ball speed) to increase the accuracy of the kick.

Ball velocity is largely dictated by foot velocity, however other factors influence the nature of impact. It has previously been reported that a substantial amount of ball speed after impact is due to the speed of the foot prior to impact when assessing seniors and junior kickers (Ball et al., 2010). However, it was also suggested that foot speed prior to impact should not be the only focus to improving kicking distance because there are several factors associated with the nature of the impact that can influence the ball speed. For example, these other impact factor influences on ball speed are: ball orientation; position of ball on foot; behaviour of the foot due to impact with the ball; and work done on the ball.

Impact efficiency

While foot–to-ball speeds were significantly larger for distance kicks, foot-to-ball speed ratio did not increase significantly. Foot-to-ball speed ratio has been used as an indicator of impact efficiency in soccer kicking (Shinkai, Nunome, Suito, Inoue, & Ikegami, 2013). In the present study, a small non-significant effect size was found between foot-to-ball speed ratio in accuracy (1.25) and distance kicks (1.28). Previous research in AF kicking also shows non-significant differences when comparing foot-to-ball speed ratios between kicking techniques. Medium non-significant differences existed between senior (1.23) and junior (1.16) distance kicking (Ball et al., 2010). Similar findings were also found between preferred (1.23) and non-preferred (1.20) kicking limbs in AF (Smith et al., 2009). After post-hoc statistical analysis by the author of the present study analysing rugby league (Ball, 2010), no significant differences in foot-to-ball speed ratios were found between 45m (1.30) and grubber (1.27) kicks ($t(11) = 0.2780$, $p > 0.05$).

No significant differences existed in the efficiency of impact however it can be suggested that a difference in the execution of kicks existed. Non-significant differences in foot-to-ball speed ratio were found in the current study and the above presented studies and is likely due to only successful kicks being analysed where a key characteristic of a successful kick is reaching an optimal efficiency. Ball et al., (2010) reported no significant difference in foot-to-ball speed ratio but found a lower correlation of foot and ball velocity in junior compared to senior kickers and suggested impact factors were the cause. The author completed post-hoc analysis that showed a significantly larger change in ankle angle existed in junior compared to senior kickers and suggested differences were caused by lower levels of strength in junior kickers. Similar findings of a greater change in ankle angle and lower correlation between foot and ball velocity existed in the present study, however, it can be suggested the reason for differences in the present study were by an alteration in technique rather than differences in strength due to the same population completing the task.

Ankle angle

Distance kicks displayed significantly lower plantar-flexion angular displacement during impact phase compared to distance kicks. These results supports the findings of Ball et al., (2010) whom stated that a firmer foot is beneficial for distance kicking. Previous research focusing on impact in soccer kicking has reported the ability to maintain body rigidity throughout impact is beneficial for distance kicking (Asami & Nolte, 1983; Lees, Asai, Andersen, Nunome, & Sterzing, 2010; Sterzing & Hennig, 2008). However, analysis within distance kicks displays contrasting results. No correlations existed between foot-to-ball speed ratio and change in ankle angle ($r = -0.16$) and moderate and strong correlations existed between change in ankle angle with impulse ($r = 0.63$), work ($r = 0.44$), peak force ($r = 0.61$) and ball velocity ($r = 0.58$). This contradicts previous research and theoretical understanding while supports findings by Nunome, Lake, Georgakis, & Stergioulas, (2006) whom reported the largest foot speed with the largest change in ankle angle. However this could be limited by the group-based analysis in the present study where changes in individuals may produce different results. Tol, Slim, van Soest, & van Dijk, (2002) associated forced plantarflexion with a greater risk of injury within distance kicking where lowering this change in ankle angle could lower the chance of injury.

The results of the present study indicate the difference in change in ankle angle is unlikely due to a passive movement of the foot where it is an active control. Significantly larger force was found in distance kicks where assuming that the point of contact remained constant a greater plantar-flexing force is expected. Visual inspection of the point of contact showed impact to occur at similar points where it is likely to be an active change. Eight out of 11 participants displayed greater plantar-flexing movements in accuracy compared to distance kicks where it is suggested that the difference change in ankle angle between distance and accuracy kicks was intentional. This change could exist to increase accuracy or to alter the flight path of the ball.

Ankle angle differed significantly between distance and accuracy kicks where it was suggested to be a method of increasing accuracy. Post-hoc calculations of ankle angle throughout the duration of impact showed significant differences in ankle angle occurred at the onset of impact until the midpoint of phase 3 with distance kicks exhibiting a higher ankle angle (Figure 5.1). Previous research has linked distance kicking with the potential to damage anatomical structures (Tol et al., 2002), indicating that ankle rigidity is provided not only by muscles, but also by bony structure within the ankle joint. At the onset of impact, there is less support provided by bony structure in accuracy kicks that could be an intentional method to lower high pressure force gradients across the foot. Previous research into soccer kicking has reported that altering the construction of shoes to reduce the high-pressure force gradients across the foot increases accuracy (Hennig & Sterzing, 2010). Comparing multiple shoes along with barefoot kicking, the author reported that uneven pressures across the ball to foot surface caused by anatomical structures could lower kicking accuracy. Different shoe constructions that increase the pressure distribution more evenly across the foot were believed to increase accuracy. It can be suggested that actively allowing a more forgiving foot during impact may be a method of lowering high pressure force gradients.

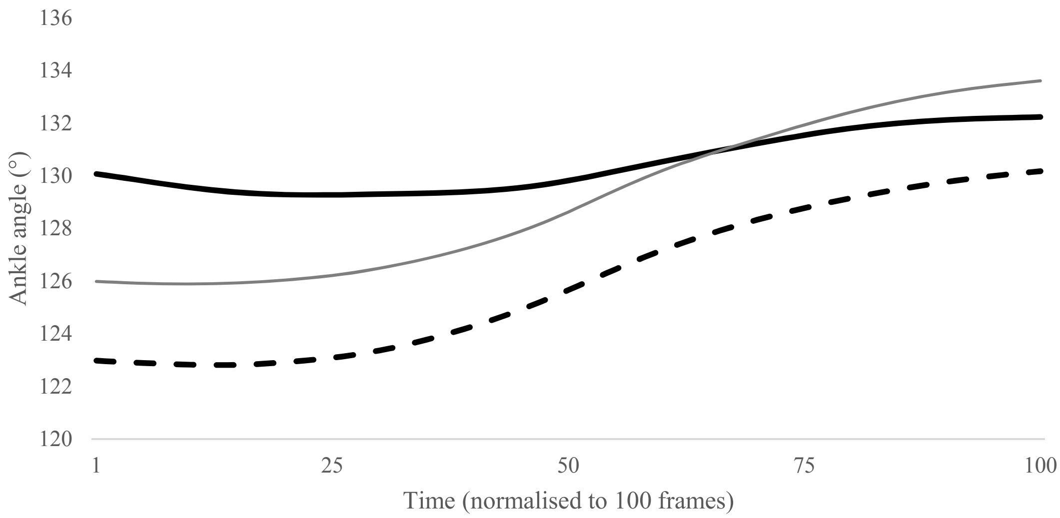

Figure 5.1. Ankle angle throughout the duration of impact of distance (solid black line) and accuracy (dashed black line) kicks. 95% confidence interval is represented by the solid grey line.

Absolute foot angle differed significantly with accuracy kicks displaying a more vertical foot orientation where it was suggested this would optimise impact to reach the desired ball trajectory. Post-hoc calculations of absolute foot angle throughout the duration of impact show that accuracy kicks displayed a significantly greater foot angle relative to the horizontal compared to distance kicks that lasted the duration of impact (Figure 5.2). As previously discussed, ball flight trajectory differed significantly between accuracy and distance kicks with accuracy kicks producing a lower trajectory by 15°. To obtain this difference in trajectory, the angle of the foot in distance kicks was more vertical. The difference between distance and accuracy kicks started at approximately 12.5° and increased to approximately 22° at the end of impact. To obtain this desired trajectory, ankle angle may have potentially been optimised to allow for a greater range of motion to combat the change in foot angle that occurs as shank angle increases.

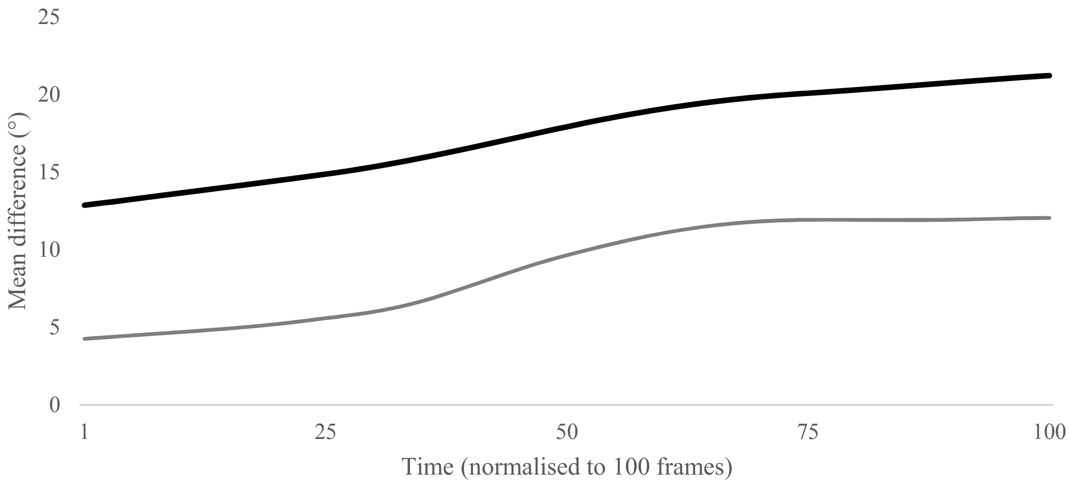

Figure 5.2. Mean difference in absolute foot angle between distance and accuracy kicks throughout the duration of impact (solid black line) and 95% confidence interval (solid grey line). Accuracy produced a more vertical foot alignment compared to distance kicks.

5.3.2 The nature of the ball

Contact time

Contact time was significantly lower for distance compared to accuracy kicking. While no study has specifically compared these two kick types, the pattern of higher foot/ball velocity kicks being associated with lower contact times has been found in AF, rugby league and soccer kicking. In AF kicking, Smith, Ball, & MacMahon, (2009) reported contact time for preferred kicking limbs (11.53ms) to be lower than non-preferred kicking limbs (12.05ms) where greater ball speed after impact occurred. Ball, (2010) reported a lower contact time in rugby league for the 45m kicks (7.2ms) compared to the grubber kick (8.8ms) while Nunome, Shinkai, & Ikegami, (2012) reported a negative correlation between ball velocity and contact time in soccer kicking that was significant ($r = -0.438$, $p < 0.05$). The association between higher implement speeds and lower contact times has also been found in other impact sports such as tennis and golf (Cross, 1999; Roberts, Jones, & Rothberg, 2001).

Significant differences in contact time found in the present study appear to be in contrast to other previous results in AF kicking. Comparing senior and junior kickers, Ball et al., (2010) reported a significant difference in force (seniors producing larger force) but reported a small effect which was not significant between the groups in contact time. Comparing 30m and 50m kicks, Ball, (2008b) reported no significant difference between contact time.

Force is estimated to be the determining factor for contact duration in striking sports. Roberts et al., (2001) reported ball contact duration in golf could be estimated via the Hertz Law of contact, where it is the resistance of an object to change in its length during impact that alters contact time when a given force is applied. Alternatively, it can be stated that when the mechanical properties of the striking objects remain constant and the force changes, contact time will change. Post-hoc correlations within the present study between force and contact time within accuracy (r = -0.85) and distance (r = -0.67) kicking produce strong relationships that are negative in direction and supports this explanation. Nunome et al., (2012) correlated ball velocity with contact time that produced a significant relationship. Post-hoc correlations within the present study within distance kicks between ball velocity and contact is insignificant (r = 0.10), however, this does not contrast the provided explanation. In the study of Nunome et al., (2012), ball speed after impact and average force will naturally correlate higher than AF kicking due to velocity of the ball prior to contact. In soccer studies, a stationary ball is used compared to AF kicking where the ball is dropped and as a result, the velocity of the ball in AF kicking is not standardised and is another variable to account for in the relationship between ball velocity and force. With this in mind, it can be suggested that in the study by Nunome et al. (2012), the correlation between force and contact time will be significant which supports the explanation introduced by Roberts et al., (2001).

All previous research in AF kicking does not rebuke the provided explanation for contact time. The small effect size found by Ball et al., (2010) appears to contrast Hertz law of contact, due to the results indicating that as average force increased so did contact time. However, this contrast is likely due to the mechanical properties of the limbs of the two different populations (juniors and seniors) completing distance kicks. Hertz law of contact requires the mechanical properties of the striking objects to remain constant in order for different magnitudes of force to alter contact time. It was reported in Ball et al., (2010) that lower levels of strength in junior players accounted for differences in impact characteristics. The results of Ball, 2008b also appear to be in contrast of Hertz law however post-hoc correlations indicate the results are unable to rebuke the explanation.

Post-hoc calculations by the author of the present study show that average force throughout impact was similar between 30m (1042N) and 50m (1129N) kicks however statistical analysis could not be completed.

Contact distance

Distance kicks produced significantly larger contact distance compared to accuracy kicks. Similar results have been reported in previous research focusing on impact in AF kicking. For example, when comparing 50m and 30m accuracy kicks, Ball, (2008b) reported a significant difference with a small effect size with 50m kicks exhibiting a contact distance of 0.24m and 0.19m for 30m kicks. In another study, comparisons between senior and junior distance kicking reported contact distances of 22cm and 20cm, respectively (Ball et al., 2010). A third study reported significantly larger differences when comparing the contact distance in the preferred limb (0.22cm) compared to the non-preferred limb (0.19cm) (Smith et al., 2009). All the presented studies also displayed significantly larger foot velocities prior to impact.

The increase in contact distance is due to the increase in foot velocity prior to impact. All research that reported significantly larger contact distance, also reported significantly larger foot velocity prior to impact. When this study correlated foot speed and contact distance, positive and moderate in strength correlations existed for accuracy ($r = 0.34$) and distance kicks ($r = 0.40$). A larger foot velocity prior to impact is going to lead to a greater deformation of the ball. In turn, larger contact distance will occur as a result of a combination between greater deformation and greater foot speed.

Work/ Impulse

The effect of kicking condition on the force-related variables of work and impulse was significant. Both variables showed a significant increase in the distance kicking condition compared to accuracy kicking. This finding is supported by previous research investigating work between similar kicking conditions (e.g. 30m to 50m accuracy kicks, senior to junior kickers, preferred to non-preferred kicking limbs). No studies in AF or rugby had used impulse as a dependent variable for statistical analysis. When comparing between 30m and 50m accuracy kicks, work was found to be significantly larger in 50m kicks (271J) compared to 30m kicks (198J) (Ball, 2008b). When comparing work between limbs, preferred kicks (225J) were significantly larger than non-preferred kicks (156J) (Smith et al., 2009). Work was also found to be significantly greater in a senior player's kick (225J) compared to junior kickers (136J) (Ball et al., 2010). While no study has specifically compared distance to accuracy kicks as seen in the current study, all significant differences were associated with different kicking distances. Correlations between ball speed and work and impulse within distance kicks were extremely strong ($r = 0.98$ and $r = 0.99$, respectively). Intuitively, a high correlation will be produced due to ball speed included in the calculations for all parameters. However, it can still be suggested that the difference in work and impulse can be associated more with the difference in kicking distances.

Ball reaction force

Peak and average force were significantly larger in distance compared to accuracy kicks. Statistical comparisons of force data throughout the duration of impact show throughout phases 2 and 3 of impact distance kicks were characterised by significantly larger force values. Throughout phases 1 and 4 of impact, no statistical differences were found. Previous research focusing on impact in AF and rugby league kicking where different kicking techniques were analysed did not report peak or average force values. Previous research in soccer kicking has documented the nature of foot and ball impact throughout the duration of contact. Shinkai et al. (2009) reported the true nature of foot and ball contact throughout the duration of impact in soccer kicking using a novel method to assess the nature of the centre of gravity of the ball. It was suggested that approximately three fourths of impact was required to accelerate the ball where the final phase of impact saw little interaction between the foot and ball. For the present study, it would be expected that during these first three of four phases of impact significant differences in force would exist between kicking types. However, the results indicate that only in phases 2 and 3 significant differences existed between kicking types. This is likely due to mostly deformation of the ball occurring in the first phase of impact.

Foot velocity prior to impact was a key determinant of force applied to the ball in both accuracy and distance kicking. Foot speed and average force correlated very highly within distance kicks ($r = 0.72$) and moderately in accuracy kicks ($r = 0.36$). It can be suggested that foot speed is a key determinant of ball reaction force, however, the reduction in correlation between foot speed and average force from distance to accuracy kicks could be caused by the in-efficiency of impact. No significant differences were found in the general shape of the force curve. This indicates that possible impact factors introduced by Ball et al., (2010) either did not have an influence when comparing accuracy to distance kicks, or do not influence force throughout any kicking types. A small non-significant difference existed between accuracy and distance kicks in foot-to-ball speed ratio however, as previously discussed only successful kicks were analysed. If the reduction in correlation is due to the in-efficiency of impact then foot to ball speed ratio may not be able to measure the highly-sensitive differences.

5.4 General Discussion

Larger foot and ball speeds, forces, work and impulse for distance kicks were expected and logical. In attempting to achieve greater distance, increasing foot speed might be expected to subsequently produce greater ball speed and in turn distance. The mechanism underlying this is likely to be related to the imparting of greater force, work and impulse on the ball during impact.

Ankle angle findings were not expected and indicated that ankle range of motion during impact could not be explained by passive forces tending to plantar-flex the foot. Rather a different strategy seemed to be adopted by players where for distance kicks, a more extended and rigid ankle, which exhibited some dorsi-flexing movement in the early stage of impact for some, was used while a 'looser' ankle was evident in accuracy kick. This finding might support the use of a rigid ankle to produce greater distanced kicks, as found in previous punt kicking (Ball et al., 2010) and soccer kicking research (Asami & Nolte, 1983; Lees, Asai, Andersen, Nunome, & Sterzing, 2010; Sterzing & Hennig, 2008). It might also be indicating players are minimising injury risk in not allowing the ankle to be forced into excessive plantar flexion, a factor found to contribute to ankle impingement injuries in soccer kicking (Tol et al., 2002). However on further analysis, two factors indicated this relationship is more complex and in need of more research. First, two players exhibited the reverse pattern where greater plantar flexion occurred in accuracy kicks. Second, within distance kick correlations indicated positive correlations existed between ankle range of motion and force, work, impulse and ball velocity. These relationships might be expected to be negative if a more rigid ankle was of greater benefit to distance kicking. Future work needs to examine this mechanism further using an intra-individual approach to determine if individuals can change efficiency/distance by increasing or decreasing ankle rigidity.

The present study has provided basic information of the profile of impact, however, future directions of research should continue to analyse the nature of impact in AF kicking with more advanced techniques. Three-dimensional impact data has been calculated in soccer and should be included in future AF kicking studies. While AF drop punt kicking is more planar compared to instep soccer kicking, other popular kicks such as the banana, snap and torpedo can only be analysed using this method. Successful vs. unsuccessful kicking also requires three-dimensional high speed video due to impact expected to occur off-centre on the foot. Change in ankle angle can also continue to be analysed throughout different kicking conditions as current coaching cues are to train players to obtain a rigid foot however the results of this study indicate otherwise. Various approach speeds should be analysed to determine influences on impact characteristics. Ball et al., (2013) stated that estimating the centre of gravity of the ball is a difficult task for a ball that is not a spherical shape which should be a strong focus.

6.0 Conclusion

The results of the study have provided quantitative information about impact between the foot and ball during AF kicking. Impact could be split into four phases as seen in rugby league (Ball, Ingleton, Peacock, & Nunome, 2013) and soccer kicking (Shinkai, Nunome, Isokawa, & Ikegami, 2009). The first phase of impact was characterised by instant deceleration of the foot and deformation of the ball where an apparent delay of the geometric centre of the ball increasing velocity that lasted approximately 2ms. The second phase of impact saw ball reaction force increase and ball velocity increased as a result. Peak force occurred three fourths of the way through phase two of impact as deformation continued until the end of the phase. Phase three saw reformation of the ball where ball velocity continued to increase as the velocity of the foot decreased. Phase four of impact saw the velocity of the foot and ball plateau. The ball travelled at a constant speed that was higher than the foot and lasted until impact ceased where little interaction between the foot and ball occurred. These findings are in accordance with Shinkai et al., (2009) whom suggested that effectual duration of impact to accelerate the ball is approximately three fourths of contact time. It is during the deformation phase of impact the foot is applying force on the ball whereas during the reformation phase the ball is applying force to the foot. It was also suggested that peak deformation does not occur at crossover point of foot and ball velocity during impact due to peak force occurring prior to the event.

Foot and ball impact characteristics differed between accuracy and distance kicks. Distance kicks displayed significantly larger foot and ball velocity, contact distance, average and peak force, work and impulse. Contact time and plantar-flexion were significantly larger in accuracy kicks. Foot to ball speed ratio did not differ. The main determinant of impact nature was the velocity of the foot however other influential factors were the nature of the foot during impact.

The nature of the foot differed between kicking techniques. Significant differences in foot velocity were the reduction in required distance and the constraint of accuracy. Impact efficiency did not differ between kicks however it was suggested that a change in execution of foot motion existed. The significant change in ankle angle between distance and accuracy kicking was suggested to be an active alteration due to larger range of motion exhibited in accuracy kicks with a lower ball reaction force. This was characterised by a lower ankle angle in accuracy kicks where it was suggested that less support was provided by bony structure within the ankle. Previous research stating that greater ankle rigidity was better for kicking was questioned after analysis within distance kicks indicated that a greater range of ankle angle motion led to higher work, impulse, peak force and ball velocity. However, it was noted this should be tested using an intra-subject study design.

The nature of the ball differed between kicking techniques. Contact time differed significantly between kicking types where discussion from other striking sports found force to be the main determinant. Work, impulse and contact distance differed and were associated with foot velocity due to the distance of kicks. Ball reaction force was expected to differ between phases 1-3 however results show differences occurred throughout phases 2 and 3. It was suggested that no differences existed due to mainly deformation of the ball occurring in phase 1 of impact.

Most results of the study were expected due to varying desired distances. Results of the profile of impact were unclear where more advanced techniques of analysing impact could assist in the description of impact. Ankle angle findings were not expected where future directions should focus on what the optimal ankle angle movement is via an intra-subject study design.

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Appendix A – Smoothing

The decision on the level of smoothing cut-off frequency was based on five components:

A.1. Optimum frequency by residual analysis

A.2. Change in parameters

A.3. Visual inspection

A.4. Previous literature

A.5. Summary

A.1. Optimum frequency by residual analysis

Using a residual analysis, the characteristics of the filter in the transition region are reflected in the decision process (Winter, 2009). This method allows for a frequency chosen where the displacement signal distortion is equal to the residual noise. As defined by Winter, (2009), residuals were calculated from equation A.1.1.

$$R(fc) = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(X_i - \ddot{X}_i)^2} \qquad \text{(equation A.1.1)}$$

Where fc = is the cutoff frequency of the filter

X_i = is rawdata at the ith sample

$\ddot{X}_i$ = is filtered data at the ith sample

A maximal distance kick was chosen for calculations. All ball flight data was removed prior to running the residual analysis to ensure that low frequency movement data did not influence the high frequency impact data. A low-pass Butterworth filter was applied with 50 samples reflected either side of the data. 6 samples of data were used in each buffer with 1 bidirectional pass. Data were smoothed using frequencies ranging from 10 up to 500Hz in increments of 10Hz.

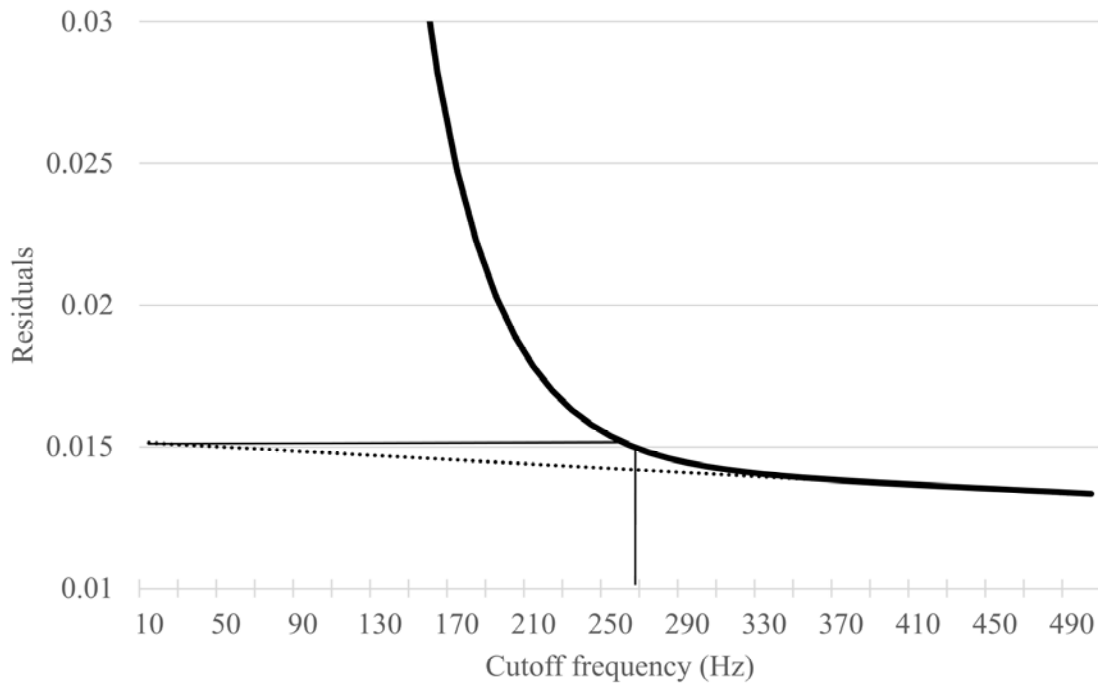

Figure A.1. Residual analysis – B1 X coordinates. Figure A.1 represents the residual analysis of the X coordinates of the marker B1 derived from a maximal distance kick. The cut off frequency calculated by residual analysis is 260Hz.

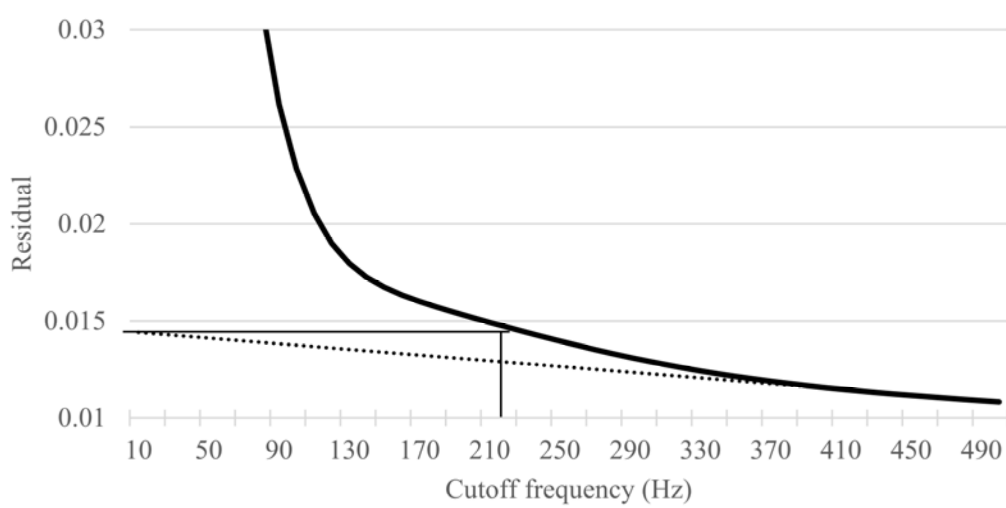

Figure A.2. Residual analysis F1 X coordinates. Figure A.2 represents the residual analysis of the X coordinates of the marker F1 derived from a maximal distance kick. The cut off frequency calculated by residual analysis is 230Hz.

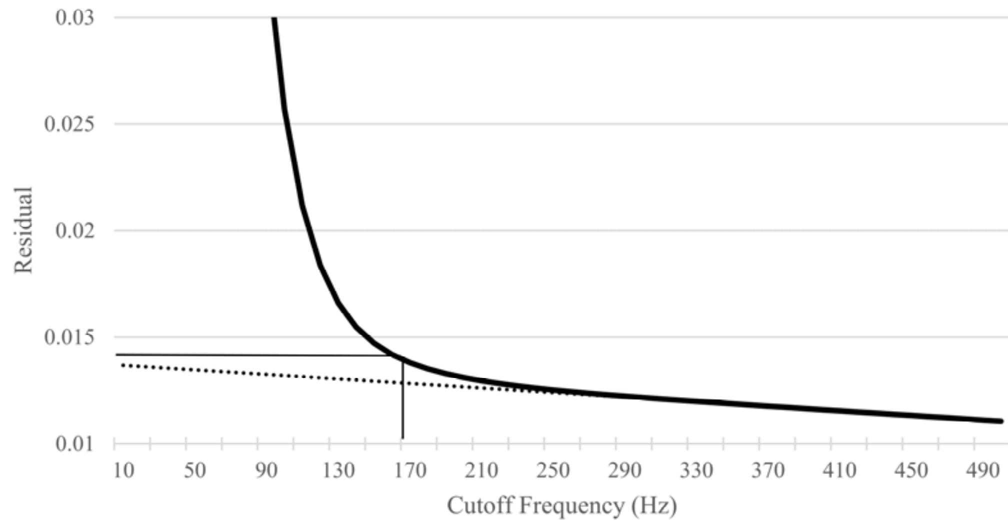

Figure A.3. Residual analysis F1 Y coordinates. Figure A3 represents the residual analysis of the Y coordinates of the marker F1 derived from a maximal distance kick. The cut off frequency calculated by residual analysis is 170Hz.

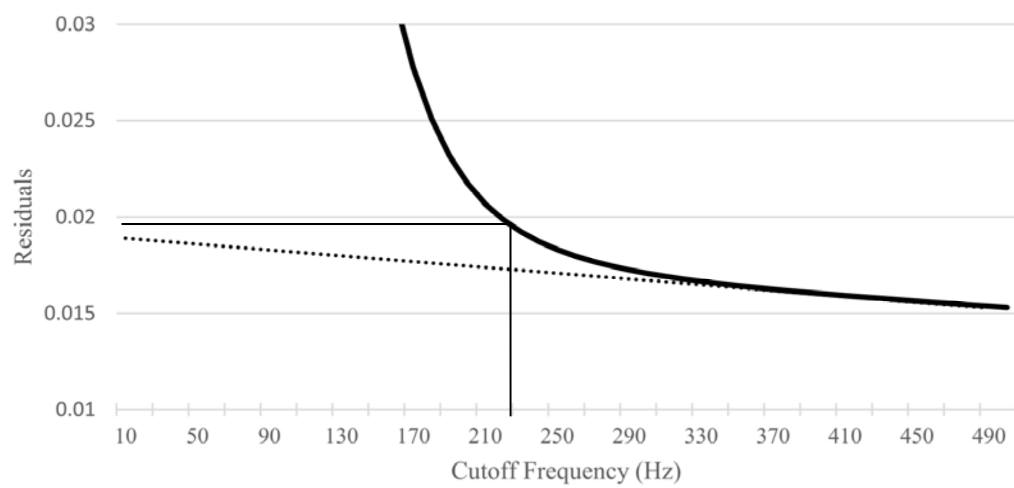

Figure A.4. The residual analysis of the Y coordinates of the marker B1 derived from a maximal distance kick. The cut off frequency calculated by residual analysis is 230Hz.

Optimum cutoff frequency derived from residual analysis indicates that the optimum range is going to lie between 170 to 260Hz. See table A.1 for a summary of the results. Residual analysis is best designed for displacement data, where the majority of the current study is going to look at velocity and force (acceleration) where the data is differentiated and double differentiated. Yu, Gabriel, Noble, & An, (1999) found that the optimum cutoff frequency derived from residual analysis was significantly lower than the true optimum, especially when sampling at a high frequency as is the case in the current study.

Table A.1. Summary of optimum cutoff frequencies derived from residual analysis (Hz)

Maximal distance kick	X	Y
B1	260	230
F1	230	170

A.2. Change in parameters

Peak and average force were calculated using a range of smoothing cut-offs to examine the effect of different cutoff frequencies. These were chosen as with double differentiation required, they would be affected most by the different smoothing cut-offs. From residual analysis, the cutoff frequency lay between 170 to 260Hz. However Yu et al., (1999) reported optimum cutoff frequency derived from residual analysis is significantly lower than optimum when working with higher sampling rates. Accordingly the low end (170 Hz) cut-off was retained but the upper end cut-off was increased to 380 Hz to accommodate this possibility that the cut-off was lower than optimal. This upper value also encompassed the 350 Hz used in previous research examining soccer kicks (Shinkai, Nunome, Isokawa, & Ikegami, 2009).

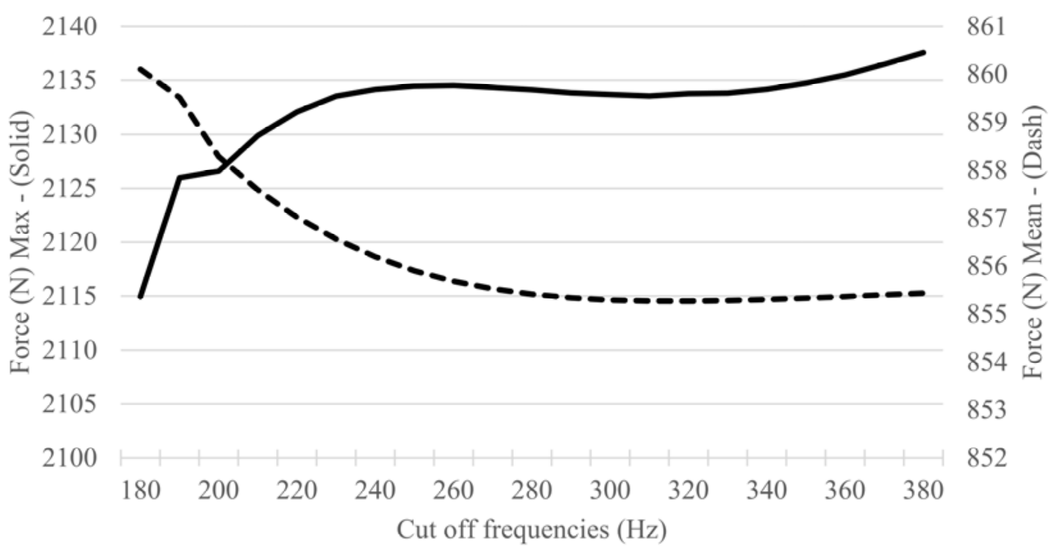

Figure A.5. Effects of different cutoff frequencies on parameters of interest - maximal force (solid line) and average force (dashed line).

As shown in figure A.5, the curves of maximal force (solid line) and average force (dashed line) show two different areas where parameters are altered due to cutoff frequencies. The optimum range when looking through maximal force is between 240 to 260Hz. As the frequency decreases the peak force starts to rapidly decrease which is an indication that the true signal is being removed. The goal is to remove as much noise without moving true signal. During this range between 240 to 260Hz the results have plateaued, where there is a difference of less than 1 newton of force. Looking at the average force (the dashed-line), the optimum frequency is higher. The data starts to plateau at around 280Hz and continues to do so past 380Hz. The figure indicates that at lower frequencies signal is being eliminated along with more noise than higher frequencies. It can be concluded that 280Hz is the lowest cutoff frequency that should be used when looking at average force.

Based on this analysis, for maximal force, values started to decline at 240 Hz indicating smoothing frequencies below this threshold started to remove signal as well as noise. For Average force this value was higher (280 Hz). It is worth noting that maximum force varied only 3 N for smoothing cutoff frequencies from 250 Hz to 380 Hz indicating it was reasonably stable through any of these frequencies.

A.3. Visual inspection

Visual inspection was used to qualitatively assess the influence of different cutoff frequencies on force (Figure A.6), foot velocity (Figure A.7) and ball velocity (Figure A.8) curves plotted against time. This was performed using raw data graphed against smoothed data using cut-offs between 240 to 300Hz.

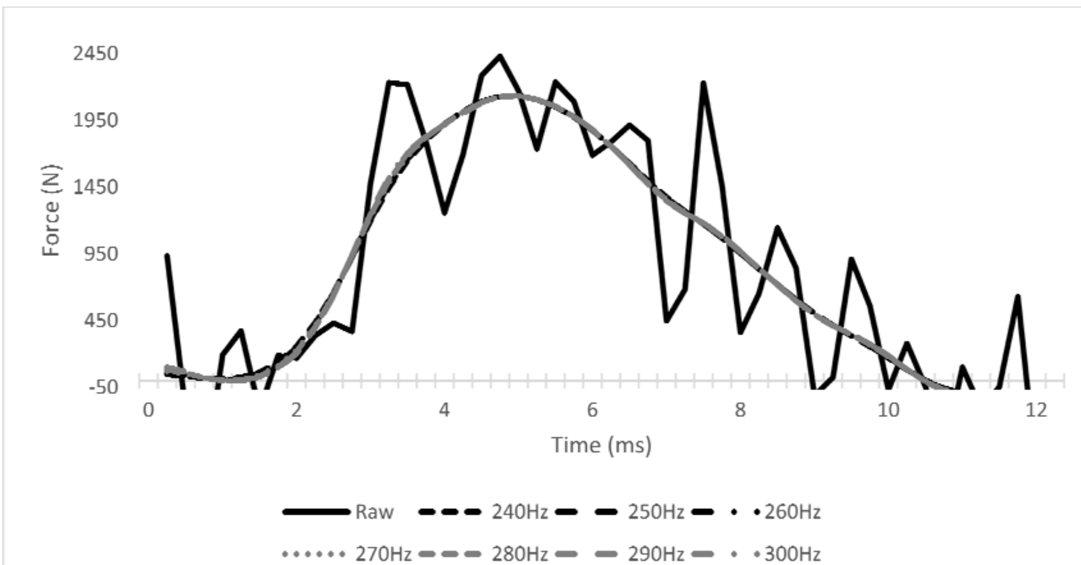

Figure A.6. Visual inspection of different cutoff frequencies on force

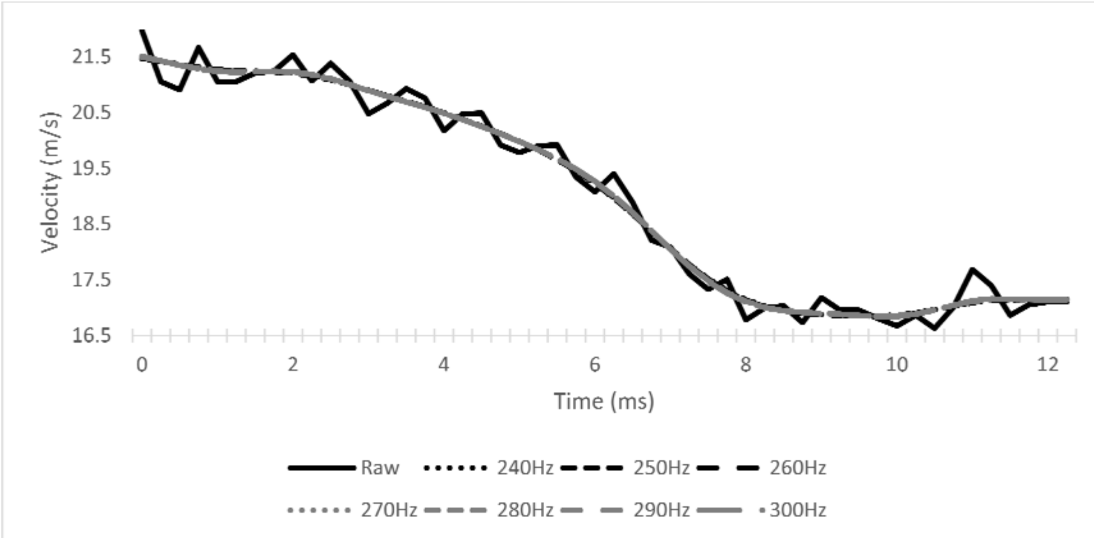

Figure A.7. Visual inspection of different cutoff frequencies on foot velocity

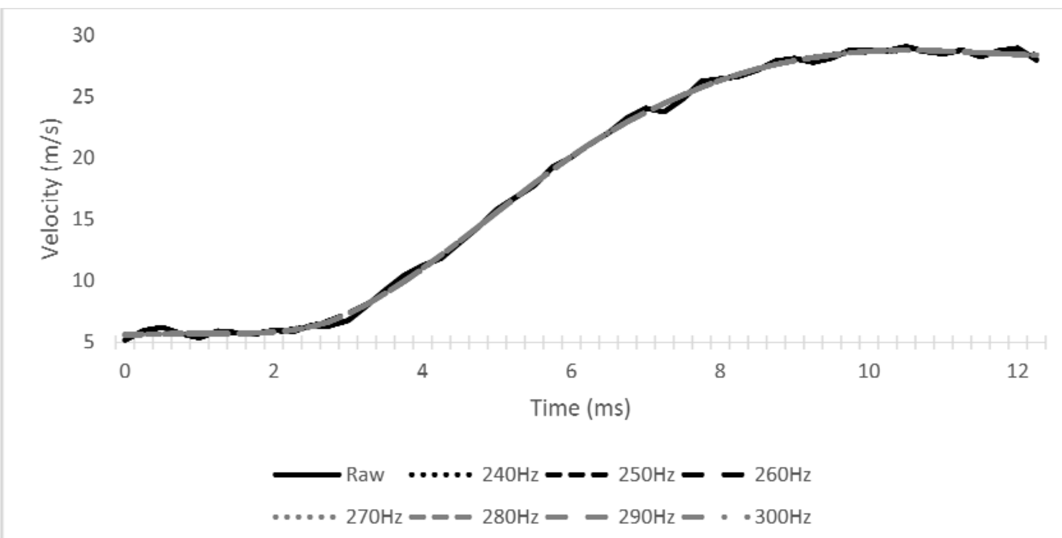

Figure A.8. Visual inspection of different cutoff frequencies on ball velocity

Figures A.6, A.7 and A.8 indicate the differences that varying cutoff frequencies have on force, foot velocity and ball velocity, respectively. Not surprisingly given the small difference in maximum and average values from section A1, there was little difference in the curves.

Due to the plateau occurring above 240Hz for maximal force and 280Hz for average force when looking at the effect of change in parameters, there is approximately a difference less than 1 N as frequencies are increased to 300Hz. This small difference showed that the continuous curves for force and foot and ball speed hardly differed when looking at cutoff frequencies between 240 to 300Hz. All of the represented cutoff frequencies appeared to be very similar, they indicate that the majority of the noise is being eliminated, where the optimum cutoff frequency will lie anywhere within the data set. As there is no clear difference of frequencies across the datasets, visual inspection can only conclude that the optimum range will lie between 240 to 300Hz.

A.4. Previous literature

Nunome, Lake, Georgakis, & Stergioulas, (2006) assessed different filters on the influence of chosen kinematic parameters to determine an optimum filter in the impact phase of soccer kicking. The study included nine male soccer players performing maximal distance instep kicks where three dimensional leg movements were captured at 1000Hz. Data included the swinging phase and the impact phase. The authors compared four data sets: a time-frequency filtering algorithm (Wigner representation filtering); a second order low pass Butterworth filter at 200Hz cutoff; resampled data at 250Hz without smoothing and finally; resampled data at 250Hz with a Butterworth filter at 10Hz. The authors found that using a modified version of a time-frequency filtering algorithm was the best. The Nunome et al (2006) study collected data at 1000Hz that included the swinging phase along with impact, compared to the current study where data was recorded at 4000Hz focusing solely on the impact phase. These different phases require different cutoff frequencies due to the swinging phase being a low frequency movement compared to the high frequency movement of foot and ball impact.

Shinkai et al., (2009) measured ball impact dynamics of maximal instep kick. Using three-dimensional data recorded at 5000Hz, a fourth order Butterworth low-pass filter at 350Hz was applied. 30 padding points were added by reflection where the extrapolated data was removed after filtering. Filtered data was compared to raw data (figure A.9) where the authors concluded that the curves of the filtered data closely matched with that of the non-smoothed data. The authors found it reasonable to assume that these smoothed changes precisely represents (without deformation) their own nature during ball impact.

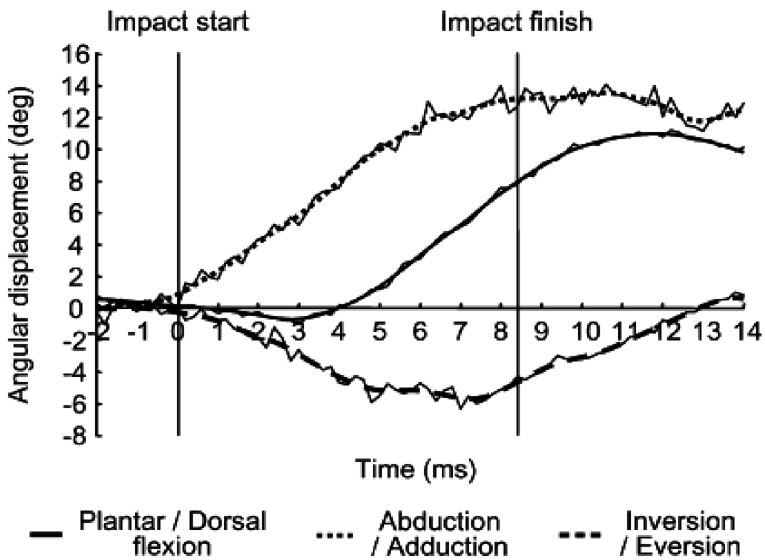

Figure A.9. Comparisons of data that is raw and smoothed with a Butterworth filter with a cutoff frequency of 350Hz. Derived from (Shinkai, Nunome, Isokawa, & Ikegami, 2009).

Tsaousidis & Zatsiorsky, (1996) recorded two dimensional data at 4000Hz focusing on the toe-kick in soccer. A second order Butterworth filter was chosen with 200Hz cutoff frequency. This frequency was chosen after the smoothness of ball speed and displacement was used as an informal criterion for deriving optimum frequency. It was suggested that this was the highest frequency at which smooth curves were obtained. Comparing this to the previous study by Shinkai et al. (2009), different parameters were chosen to assess an appropriate cutoff frequency: angular displacement compared to ball speed and displacement for Shinkai et al. (2009) and Tsaousidis & Zatsiorsky (1996) respectively. Comparing the current study with the presented study the frame rates are both the same at 4000Hz which is a good indication to an optimum cutoff frequency.

Previous literature has shown various cutoff frequencies utilised for smoothing data recorded during impact. Optimum cutoff frequencies vary between 200 to 350Hz as well as using a modified version of a time-frequency filtering algorithm. The time-frequency filtering algorithm was found to be optimum with looking at the final swinging phase and impact phase where there is a combination of low frequency and high frequency movements. The data was sampled at 1000Hz compared to 4000Hz in the current study which will have to be adjusted if it were to be used. The current study is focusing solely on the impact phase where there is only an impact phase and thus a slow frequency movement does not need to be accommodated for and thus it is concluded that the time-frequency filtering algorithm is not suitable. The other two studies focusing solely on impact varied greatly between 200Hz (Tsaousidis & Zatsiorsky, 1996) and 350Hz (Shinkai et al., 2009). Different parameters were chosen by the authors to see which cutoff frequency was optimum. However the filtered data used by Shinkai et al. (2009) was believed to match the raw data, where a smooth curve was not obtained. A smooth curve was the criteria used by Tsaousidis & Zatsiorsky (1996) which is obtained by having a lower cutoff frequency. This suggests that an optimum frequency is going to lie within the range of 200 to 350Hz. It can be concluded that an optimum cutoff frequency based on previous literature is going to lie within the range of 200 to 350Hz for recording data at 4000 to 5000Hz.

A.5 Summary

Four different criteria were used to find an optimum cutoff frequency: residual analysis; the change in parameters; a visual inspection of data transformation and previous literature. Results are shown below in table A.2.

Results from the residual analysis indicate that the optimum frequency is going to lie between 170 to 260Hz. However Yu et al. (1999) found that the optimum frequency derived from residual analysis is significantly lower than the true optimal, especially at high frequencies such as the current study. Results from chosen parameters indicates that the optimum frequency for maximum force is 240Hz and 280Hz for mean force. These results follow on from the findings presented by Yu et al. (1999) due to a higher optimum range. Visual inspection of the results found that within this range derived from chosen parameters minor differences occurred where the range could not be decreased. Previous literature has shown that the optimal range to smooth data focusing solely on impact is going to lie at approximately 200Hz for smooth curves of displacement and ball speeds, or 350Hz for 5000Hz data angular displacement data where the smoothed data best represents the raw data. With all these considerations, the chosen study has decided to use a cutoff frequency of 280Hz with 50 samples reflected and 1 bidirectional pass.

Table A.2. Optimum cutoff frequencies from different criteria

Method	Range
Residual analysis	170 – 260Hz
Chosen parameters	240/ 280Hz
	Maximum/ average force
Visual inspection	240 – 300Hz
Previous literature	200 – 350Hz

Appendix B – confidence intervals

Confidence intervals as defined by Welkowitz, Cohen, & Lea, (2012) were used to graphically present the statistical analysis of continuous data. These statistical confidence intervals are based on comparing the difference between two means, where a 2-step process is required to graphically present the data.

1. Calculating the confidence intervals based on the difference between two means. Using equation B.1.1, confidence intervals were established where Figure B.1 graphically displays the results of hypothetical data. To determine whether significant differences existed within the hypothetical data, the difference between two means ($\mu_a - \mu_b$) (solid black line) must lay between the two confidence intervals, while the two confidence intervals must not overlap the X-axis. This occurs throughout the entire duration in the presented hypothetical data.

$$D - t_{crit}S_D \leq \mu_D \leq D + t_{crit}S_D \quad \text{(B.1.1)}$$

Where

D = the difference of the group means for each data point

t_{crit} = the critical value of *t* obtained from *t* table that corresponds to 1-tail p = 0.05

$S_D = \frac{Standard\ deviation\ of\ the\ difference\ of\ the\ means}{\sqrt{Number\ of\ participants}}$

2. The statistical analysis was applied to the original data. In order to graphically present the statistical analysis for the continuous data, two separate graphs would have to be generated; one for the original data and one for the statistical analysis. To efficiently present the data, the statistical analysis was combined with the original data where the quantitative information of the data and the statistical

analysis were presented in one figure (Figure B.2). This was possible by adding the original (μ_a) signal to the upper and lower confidence intervals.

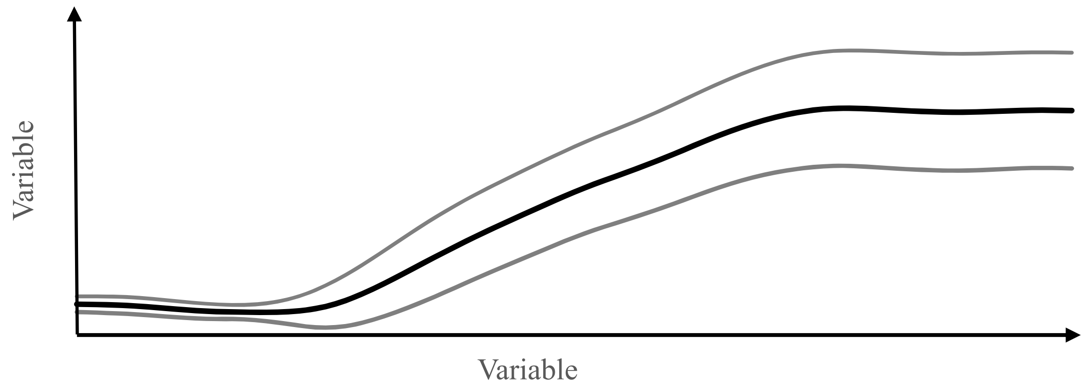

Figure B.1. Hypothetical data showing the difference between the means (solid black line) and upper and lower (solid grey lines) confidence intervals. Confidence intervals were calculated using 95% confidence intervals. As the difference of means lies within this range, the null hypothesis can be rejected.

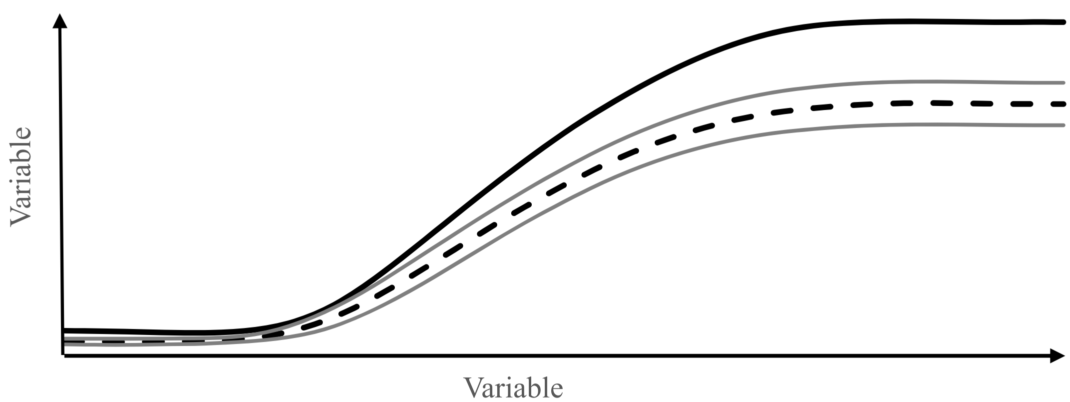

Figure B.2. Hypothetical data showing the lower confidence interval (solid grey line), higher data series (solid black line) and lower data series (dashed black line). The upper data series has exceeded the lower confidence interval and a statistical difference has occured.

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INFORMATION TO PARTICIPANTS INVOLVED IN RESEARCH

You are invited to participate

You are invited to participate in a research project entitled "*Comparisons of foot to ball interaction in Australian Football kicking in elite males".*

This project is being conducted by a student researcher James Peacock as part of Honours at Victoria University under the supervision of Dr Kevin Ball from the College of Sport and Exercise Science.

Project explanation

The study aims to study the foot to ball interaction in the drop punt kick involved in Australian Football. A number of parameters will be investigated to determine the differences between the different drop punt kicks used in Australian Football.

Data will be recorded by two camera systems; Vicon 3d system and high speed video capture in 2d. The Vicon data will capture your whole body, but no data will be identifiable as the system only registers the reflective markers. The high speed video capture will record data from the waist down, where there will only be minimal identifiable data.

What will I be asked to do?

Participants will be asked to come into the biomechanics laboratory located at Victoria University, Footscray Park. They will come in for 1 session which will run for approximately 4 hours. Participants will be asked to wear running shorts and football boots whilst the testing occurs. Participants will have 9 singular reflective markers and 2 cluster reflective markers placed on their wrist, hips, thigh, knee, shank, ankle and foot of the preferred kicking leg. Please note during testing Participants will be asked to remove their shirt as markers will need to be visible by cameras recording the data.

After a 10 minute warm up consisting of running, stretching and kicking, Participants will be required to complete 8 kicks in the laboratory. These 8 kicks are;

2 x Buckley 20m kicks
2 x 30m shot at goal with a slow approach
2 x 30m shot at goal with a fast approach
2 x maximal distance.

Participants will be using a Sherrin football, which is currently used in the Australian Football League.

What will I gain from participating?

Participants will be assisting in research of a skill that is highly important. They may also receive some feedback on their kicking technique with the idea of improving their skill.

How will the information I give be used?

All videos recorded during the testing session will be analysed using computer software. The results will then be exported to Microsoft Excel where the data can be interpreted and compared among the different kicking styles as well as past research.

What are the potential risks of participating in this project?

There are minimal risks as the tasks undertaken during the testing session are regularly completed during training and game situations. All Participants can freely stop testing at any point of time without any consequence. No data will be sent to coaches/ staff unless organised prior to the Participants giving informed consent.

If an adverse event occurs, there will be a member on the research team that is competent in first aid and there is access to phones to contact the appropriate resources (i.e. ambulance).

If the need arises, there is a registered psychologist that participants can contact at no cost;

Dr Harriet Speed, Ph: (03) 9919 5412, Email: Harriet.Speed@vu.edu.au.

How will this project be conducted?

Participants will be required to wear running shorts and football boots (or whatever is used in games). They will be asked to remove any shirts once marker placement begins. Participants will have 9 reflective markers in total attached to their wrist, hip, thigh, shank, knee, ankle and foot on their preferred side of the body.

A 10 minute warm up consisting of running, dynamic stretching and kicking will be completed before testing will begin.

Participants will then commence testing. They will be asked to complete 2 of the following 4 kicking tests;

- Buckley 20 meter kick
- Shot at a goal 30m away with a slow approach
- Shot at a goal 30m away with a fast approach

- maximal kick with self-selected run up

Who is conducting the study?

Victoria University

Footscray Park Campus
College of Sport and Exercise Science

Chief investigator:
Dr Kevin Ball (PhD in sports biomechanics)

kevin.ball@vu.edu.au

0404 876 480

Student Researcher:

James Peacock (Completing Bachelor of Applied Science (Honours) in biomechanics)

james.peacock@live.vu.edu.au

0432 404 159

Any queries about your participation in this project may be directed to the Chief Investigator listed above.

If you have any queries or complaints about the way you have been treated, you may contact the Ethics Secretary, Victoria University Human Research Ethics Committee, Office for Research, Victoria University, PO Box 14428, Melbourne, VIC, 8001 or phone (03) 9919 4781.

CONSENT FORM FOR PARTICIPANTS INVOLVED IN RESEARCH

INFORMATION TO PARTICIPANTS:

We would like to invite you to be a part of a study into…

Comparing kinetic variables between maximal and accuracy kicks in elite male Australian Footballers during the foot to ball contact phase of a drop punt kick. Each subject will have 9 reflective markers placed on their wrist, hip, thigh, shank, knee, ankle and foot on their preferred leg. They will undergo a 10 minute warm up to reduce any chance of injury occurring whilst completing the test.

These kicks will be recorded using a high speed video camera recording at 4000Hz which will record data from the hip down. The Vicon 3d system records information using infrared light so there will not be any actual images of your body.

Data will then be analysed with ProAnalyst and Vicon Motus software where it is then exported to Microsoft Excel to interpret the results before being published.

CERTIFICATION BY SUBJECT

I, ________________________________

of ________________________________

certify that I am at least 18 years old* and that I am voluntarily giving my consent to participate in the study:

"comparisons of foot to ball interaction in Australian Football in elite males" being conducted at Victoria University by: Dr Kevin Ball

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I certify that the objectives of the study, together with any risks and safeguards associated with the procedures listed hereunder to be carried out in the research, have been fully explained to me by:

James Peacock

and that I freely consent to participation involving the below mentioned procedures:

- Wearing only football boots and running shorts
- Have 9 reflective markers placed on wrist, hips, thigh, shank, knee, ankle and feet on the preferred side of the body
- Conduct a 10 minute warm up
- Complete 8 kicks in total;
    - 2 x Buckley 20m kicks
    - 2 x 30m shots at goal 30m away with a slow approach
    - 2 x 30m shots at goal 30m away with a fast approach
    - 2 x maximal distance kicks
- Have these kicks recorded using high speed video cameras and Vicon 3d system
- Data be analysed with ProAnalyst and Vicon Motus software then exported to Microsoft Excel

I certify that I have had the opportunity to have any questions answered and that I understand that I can withdraw from this study at any time and that this withdrawal will not jeopardise me in any way.

I have been informed that the information I provide will be kept confidential.

Signed:______________________________

Date: ________________________________

Any queries about your participation in this project may be directed to the researcher

Dr Kevin Ball

0404 876 480

If you have any queries or complaints about the way you have been treated, you may contact the Ethics Secretary, Victoria University Human Research Ethics Committee, Office for Research, Victoria University, PO Box 14428, Melbourne, VIC, 8001 or phone (03) 9919 4781.

[*please note: Where the participant/s are aged under 18, separate parental consent is required; where the participant/s are unable to answer for themselves due to mental illness or disability, parental or guardian consent may be required.]