THE IMPACT PHASE OF DROP PUNT KICKING: VALIDATION AND EXPERIMENTAL DATA OF A MECHANICAL KICKING LIMB

James Peacock[1,2] and Kevin Ball[1,2]

Institute of Sports, Exercise and Active Living (ISEAL), Victoria University, Footscray, Australia[1]
College of Sport and Exercise Science, Victoria University, Footscray, Australia[2]

The purpose of this study was to validate a mechanical kicking limb and analyse changes in foot speed on impact characteristics of drop punt kicking. Foot speed was recorded as 9.1 – 21.2 m/s, and covered a range of kick distances. Ball speed (13.0 – 29.7 m/s), contact distance (10.7 – 20.2 cm) and contact time (14.75 – 11.75 ms) were comparable to drop punt kicking. Impact efficiency (F:B ratio = 1.37 – 1.48, coefficient of restitution = 0.66 – 0.79) were high, caused by near perfect rigidity in the design of the limb. Overall, the limb was found to be a valid representation of a human performer. Foot speed displayed significant relationships with ball speed (r = 0.998), contact time (r = -0.89), contact distance (r = 0.99) and F:B ratio (r = -0.694). The relationship between foot speed and COR (-0.347) was not significant.

KEY WORDS: Australian football, high speed video, collisions, energy transfer.

INTRODUCTION: The human limbs (hands, feet) are frequently used among ball sports to strike the ball at a specific location directing it onto a desired flight path (i.e. volleyball 'spike', football 'kick'). Across the football codes, the execution of the entire kicking skill differs due to the shape of the ball used and the constraints of performing each kick. For example, a spherical ball is kicked off the ground in soccer and an ellipsoidal ball is dropped from the hand prior to impact in drop punt kicking.

Impact phase research has, for the most part, yielded similar results but with some notable exceptions. Despite the different executions of the skills, four phases through the impact phase have been identified with similar patterns reported in soccer and drop punt kicking (Peacock, 2013; Shinkai, 2009). On the other hand, relationships between some impact characteristics have not been consistent across the codes. An increase in foot speed has been linked to decreased contact time in soccer kicking (Nunome, Ball & Shinkai, 2014). For drop punt kicking, this relationship has been similarly found in one comparison of kicking tasks (Peacock, 2013), but has not been found in other comparisons (Ball, 2008b; Ball, Smith & MacMahon, 2010; Smith, Ball & MacMahon, 2009). Further, foot to ball speed ratio (F:B ratio) is considered a good measure of impact efficiency and a medium, positive relationship has been identified with ankle rigidity (Shinkai, Nunome, Suito, Inoue & Ikegami, 2013). It is somewhat expected F:B ratio and ankle rigidity are linked due to relationships between increased rigidity and ball speed in another soccer kicking study (Asami & Nolte, 1983). For drop punt kicking however, comparisons of kicking groups found the measure to not differ significantly when rigidity was increased (Ball, et al., 2010; Peacock, 2013).

Mechanical testing is an important addition to analyse the impact phase. An increased variability is expected between kicking trials of performer-based studies, particularly in drop punt kicking due to the execution in the skill where the ellipsoidal ball is dropped from the hand prior to impacting the foot. Mechanical testing will allow for the isolation of specific variables so a methodical exploration is made available if found to be valid, and thus should be used in conjunction with performer-based studies. The aim of the present study was to validate a mechanical kicking limb by using previous literature and analyse changes in foot speed on impact characteristics during punt kicking.

METHODS: A mechanical kicking limb performed punt kicks using a standard AF ball (Sherrin 'Match Ball', inflation: 69 kPa). Limb construction was based off information found in the literature, including just the shank and foot segments rotating about a fixed point representing the knee. These lower limb segments were found to be most influential during the impact phase, and so the thigh was not included (Andersen, Dörge & Thomsen, 1999; Ball, 2008a). The shank was constructed from a metal frame, with length (0.455 m) and mass (5.8 kg) similar to a typical AF player (height = 1.85m, mass = 85kg) (Winter, 1990). The shape of the impacting object has been identified to influence impact characteristics (Bull Andersen, Kristensen & Sorensen, 2008), so to obtain the correct foot impacting area, impact location on the ball and relative foot-to-ball angle, a human foot was scanned and printed as a rigid body whilst in a plantar-flexed position (Peacock, 2013) and attached to the shank.

The limb was validated by using the results found in the literature of AF and soccer kicking and a range of foot speeds were generated while keeping all other impact characteristics constant across the kicking trials. Three reflective markers were attached to both foot and ball. Data points were tracked at 4,000 Hz from three high speed video cameras (Photron SA3 and MC2, Photron Inc., USA) and reproduced in 3d using ProAnalyst (Xcitex Inc., USA) and Visual3d software (C-Motion Inc., USA). A low pass Butterworth filter of 280Hz smoothed all data (Peacock, 2013). Impact characteristics were calculated using Matlab software (The Mathworks Inc., USA). Pearson's correlation calculated the relationship between foot speed with impact characteristics.

The centre of the foot and ball were treated as a virtual landmark based off their tracking markers. Using these virtual landmarks, foot and ball speed were averaged over five frames before and after impact. F:B ratio and coefficient of restitution (COR) were computed using these measures. Contact time was visually identified using from one of the high speed video cameras located perpendicular to impact. Contact distance was measured by the distance the centre of the ball travelled from contact to release. Effective mass was calculated using conservation of momentum equations (Shinkai, et al., 2013).

RESULTS: The mechanical limb generated a range of foot speeds between 9.1 to 21.2 m/s. Ball speed was 13.0 – 29.7 m/s, and correlated significantly with foot speed ($r = 0.998$, Figure 1A). Contact distance was 10.7 – 20.2 cm and correlated significantly with foot speed ($r = 0.990$). Contact time was 14.75 – 11.75 ms, and correlated significantly with foot speed ($r = -0.890$). Foot to ball speed ratio (Figure 1B) was 1.48 – 1.39 and correlated significantly with foot speed ($r = -0.694$). Though not significant, COR (0.75 – 0.67) displayed a moderate relationship with foot speed (Figure 1B, $r = -0.347$). Effective mass was calculated to be 2.29 ± 0.19 kg across the kicking trials.

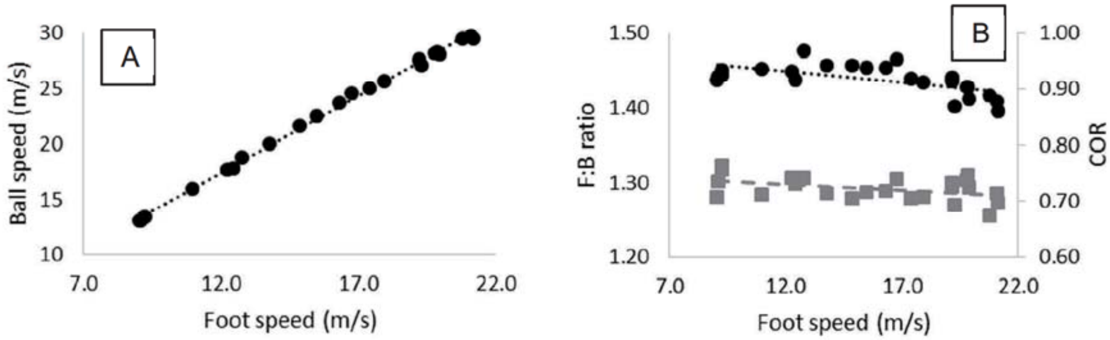

Figure 1: Correlations between foot speed with ball speed (A), F:B ratio (B, black round ticks, primary axis) and COR (B, grey square ticks, secondary axis).

DISCUSSION: The foot speeds recorded are similar to performers' kicks of varying distance. The foot speed of drop punt kicking has ranged from 17.7 m/s for 20m kicks and 22.1 m/s for maximal distance (Peacock, 2013). The 17.7 m/s recorded for 20m kicks in Peacock (2013) were also considered high for the kick distance, due to a task specific strategy by the elite performers to maximise accuracy. The foot speeds of the present study (9.1 to 21.2 m/s) are

therefore considered representative of kicks ranging in distance from 10 to 60 m (maximal distance), and the limb was successfully designed to cover a range of kick distances.
The impact characteristics indicate the mechanical limb was a very close representation of a human performer during the impact phase. Ball speed, contact time, contact distance and effective mass were similar to those recorded in AF (Table 1), however, F:B ratio was slightly higher. In soccer kicking where performers had a calculated effective mass comparable to that of the present study, F:B ratio was found to be in the range of 1.37 – 1.53 (Shinkai, 2013). These values are very similar to that of the present study, and indicate the mechanical limb was almost a perfect representation of the impact phase with only F:B ratio being slightly higher.

Table 1: Summary of impact characteristics across the literature of AF kicking.

Study	Ball speed (m/s)	Contact distance (cm)	Contact time (ms)	Effective mass (kg)	F:B ratio
Present study	13.0–29.7	10.7–20.2	14.75–11.75	2.29 ± 0.19	1.48–1.39
Peacock (2013)	22.1 ± 1.1	20.3 ± 2.4	13.2 ± 1.4	2.39 ± N/A	1.25 ± 0.04
Peacock (2013)	28.1 ± 2.5	22.8 ± 2.9	12.1 ± 1.3	2.04 ± N/A	1.28 ± 0.06
Smith et al. (2009)	32.6 ± 4.4	22 ± 2	11.53 ± 1.25	N/A	1.23 ± 0.11

The slightly higher value of F:B ratio is considered to be due to two factors of the limb's design. Firstly, there was no rotational displacement about the ankle and; secondly, there was no shoe attached to the foot. This indicates the limb represented near perfect rigidity throughout the impact phase. Future designs should consider implementing reduced rigidity about the ankle and foot, to analyse ankle motion strategies (Peacock, 2013).
Foot speed correlated almost perfectly with ball speed and contact distance. Previous comparisons of kick distances have displayed ball speed and contact distance to increase with foot speed (Ball, 2008b; Peacock, 2013). As expected, this shows increases in foot speed should be made by players to increase ball speed if they are able to keep all other impact characteristics constant. The increased contact distance was possibly caused by greater deformation of the ball, but, this was not measured. As noted by Nunome, et al., (2014), a method to calculate the deformation of an ellipsoidal shaped ball should be developed to substantiate this claim.
Impact efficiency, as indicated by F:B ratio, decreased as foot speed increased. Contrasts exist in the literature of F:B ratio in comparisons of drop punt kicking. Though ankle rigidity was not analysed in this study, the studies by Ball et al., (2010) and Peacock (2013) reported a significantly larger foot speed in the conditions of increased ankle rigidity, and thus a two-fold effect may have taken place: increased foot speed would have decreased F:B ratio, but an increased ankle rigidity may have increased F:B ratio. To confirm this hypothesis, future studies should analyse the link between ankle rigidity and impact efficiency while variability in foot speed is minimised.
Although not significant, the relationship between foot speed and COR was negative with a medium effect. A previous analysis using a pendulum to analyse the impact of soccer kicking reported COR decreased with increases in pendulum speed (Andersen, Kristensen & Sorensen, 2008). Further, this negative relationship between foot speeds and COR is found in other impacts of sporting codes (Cross, 2013). This literature suggests a negative relationship between foot speed and COR should exist, however the cause behind the non-significance of this relationship could not be explained by the results calculated. Possibilities may include the aging effect of the ball or variances in manually placing the ball on the kicking tee between trials, however further work is required.
Contact time decreased as foot speed increased, a similar mechanism to soccer kicking (Nunome et al., 2014). This has been previously identified in a comparison of accuracy and

maximal distance drop punt kicks (Peacock, 2013), however, dissimilar results have been reported in other comparisons (Ball, 2008b; Ball, Smith & MacMahon, 2010; Smith, Ball & MacMahon, 2009). The exact reasoning behind the mixed results of drop punt kicking is beyond the scope of this study, but a high variability can exist between trials and possibly influenced these previous studies. The results of the present study and Peacock (2013) indicate the relationship between foot speed and contact time is not specific to just soccer kicking, but also punt kicking. This also highlights the need to conduct more mechanical testing due to the ability to investigate individual parameters.

CONCLUSION: This study successfully validated a mechanical kicking limb and analysed the change in foot speed on impact characteristics. The design of the limb was found to be a very close representation of a human performer during drop punt kicks of various distances, and future designs should consider implementing reduced rigidity about the ankle and foot to decrease impact efficiency. Foot speed was found to produce relationships with the measured impact characteristics, excluding COR.

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