THE RELATIONSHIP BETWEEN IMPACT CHARACTERSITICS AND FORCED PLANTAR-FLEXION DURING FOOTBALL KICKING

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Reducing the forced plantar-flexion during impact of kicking is beneficial to kick performance. The aim of the present study was to identify the relationship between three impact characteristics with plantar-flexion; ankle stiffness, impact location and foot speed. By using a mechanical kicking machine to control impact characteristics, three separate data sets for each impact characteristics were created from high-speed-video camera (4,000 Hz). Relationships were determined from 1st, 2nd or 3rd order bivariate regressions. A linear relationship existed for joint stiffness, meaning a players' strength can reduce plantar-flexion. A 2nd order relationship was identified for impact location and impacting the ball closer to the ankle decreased plantar-flexion. A 3rd order relationship was identified for foot speed and dorsi-flexing at the start of impact reduced plantar-flexion.

KEY WORDS: rigidity, kick performance, technique, strength

INTRODUCTION: Kicking is an important skill across the football codes. Depending on the specific code, it can be the only or one of few methods to score goals. When a player impacts the ball with their foot, the ankle is passively plantar flexed due to the high forces and short time period (Shinkai, Nunome, Isokawa & Ikegami, 2009), and the interaction between foot and ball is determined by the initial conditions at impact start (Nunome, Lake, Georgakis, & Stergioulas 2006).

Ankle motion is an important factor for kick performance, and reduced plantar-flexion is beneficial to ball velocity and kick distance (Asami & Nolte, 1983; Peacock, Ball, & Taylor, 2017). A more rigid ankle can reduce the forced plantar-flexion, and rigidity can be increased when the ankle nears the end of plantar-flexion range of motion by relying on the anatomical structures (Peacock et al., 2017; Sterzing & Hennig, 2008). Although the interaction during impact is considered passive, Peacock et al., (2017) suggested rigidity can be actively altered between kicks by controlling the initial conditions of impact.

To date, this is only strategy established across a number of studies that players can use to improve kicking performance by reducing the forced plantar-flexion during impact. Ball et al., (2010) compared senior to junior players, and suggested the strength of the senior players caused a reduced plantar-flexion, however other impact characteristics of foot speed, impact location, ball orientation and work may have also influenced impact, and possibly caused the difference in plantar-flexion. This highlights the need to analyse the interaction under a controlled setting, because a number of confounding impact characteristics can influence ankle motion. The aim of the present study was to use a mechanical kicking machine to systematically identify the relationship between three impact characteristics with ankle plantar-flexion: joint stiffness to represent the strength of a player; impact location on the foot; and foot speed.

METHODS: A kicking machine (Figure 1A) performed kicks with an Australian Football ball (Sherrin 'Match' Ball; inflation: 69kPa). This kicking machine has been previously validated to replicate the impact phase of punt kicking featuring a rigid ankle (Peacock & Ball, 2016), but the addition of a spring mechanism to control plantar-flexion was included for this study. The spring mechanism preventing plantar-flexion could be set between a force of 1,700 to 11,100 N, or torque of 68 to 444 Nm when multiplied by the radius of 4cm between the tendons and ankle joint. This translated to an approximate change in plantar-flexion of 3.0 to 16.3°. A mechanical spring was considered valid in replicating the anatomical structures that prevent plantar-flexion during impact, as both the human ankle and the mechanical spring are passive in nature during impact (Nunome et al., 2006). Pilot work also identified the spring mechanism to produce a similar pattern and magnitude of the time-series ankle motion to previous literature (Asami & Nolte, 1983; Ball et al., 2010; Peacock et al., 2017; Shinkai et al., 2009), further proving the appropriateness of the spring mechanism.

Three separate data sets were created to answer the aims of the study; systematically changing foot speed, impact location and joint rigidity while all other impact characteristics were held constant. The baseline setting comprised a foot speed of 16.5 m/s, impact location 1 cm distally from the foot centre, and ankle stiffness of 3,300 N. The foot speed data set was adjusted between the range of 9.3 to 21.8 m/s over 11 increments. The impact location data set was comprised 11 increments between an impact location -0.5 to 4.2 cm in the distal direction from the foot centre. Joint rigidity was controlled by altering the tension of the spring mechanism preventing plantar-flexion, with rigidity between the range 1,700 to 11,100 N over 23 increments.

Two-dimensional data of the sagittal plane were captured at 4,000Hz using high speed video camera (Photron SA3, Photron Inc., USA). Markers attached to key points of the limb and ball were tracked using ProAnalyst software (Xcitex Inc., USA), and exported to Visual3d software (C-Motion Inc., USA) and Matlab software (The Mathworks Inc., USA) for analysis. Impact characteristics calculated were foot velocity, ankle angle and impact location. Foot velocity and ankle angle data were smoothed with a low-pass Butterworth filter (170 Hz). The choice of cut-off frequency was based on three criteria; Direct Fourier Transform analysis, visual inspection of data curves at different frequencies and previous literature. Impact location on the dorsal aspect of the foot was calculated by modelling the ball shell as an ellipse and the foot as a linear line, and calculating the point of intersection at ball contact.

Bivariate regression analysis (1st, 2nd, 3rd order) was used to determine the most appropriate relationship between each impact characteristic and plantar-flexion. The significance test from Hayes (1970), values of R^2, visual inspection of each scatterplot and significance ($P < 0.05$) were used to identify the most appropriate relationship of the three. Bivariate outliers were screened from inspection of the scatterplots.

Figure 1. The kicking machine (A) and limb with spring mechanism (B).

RESULTS: Across the joint stiffness data set, a linear relationship was identified with plantar-flexion (Figure 2A). This was negative in direction, meaning plantar-flexion decreased as joint stiffness increased. A 2nd order relationship was identified in the impact location data set (Figure 2B). For the foot speed data set, the 3rd order regression was the most appropriate relationship (Figure 3A). This identified change in ankle angle was maximum between the range of 14 to 22 m/s.

DISCUSSION: A negative linear relationship was identified between joint stiffness and ankle plantar-flexion. The results of the present study represent a similar finding to Ball, et al., (2010), whom suggested the muscular strength of a player can influence ankle rigidity. The increase in tension from the spring mechanism has shown to decrease the forced plantar-flexion, where an increase in the tension produced from muscles and/ or ligaments preventing forced plantar-flexion in a human limb would likely yield a similar result. This indicates an increased strength can lead to a decreased forced plantar-flexion, and as recommended by Ball et al., (2010), players with low rigidity about the ankle should include strength training reduce the forced plantar-flexion during impact.

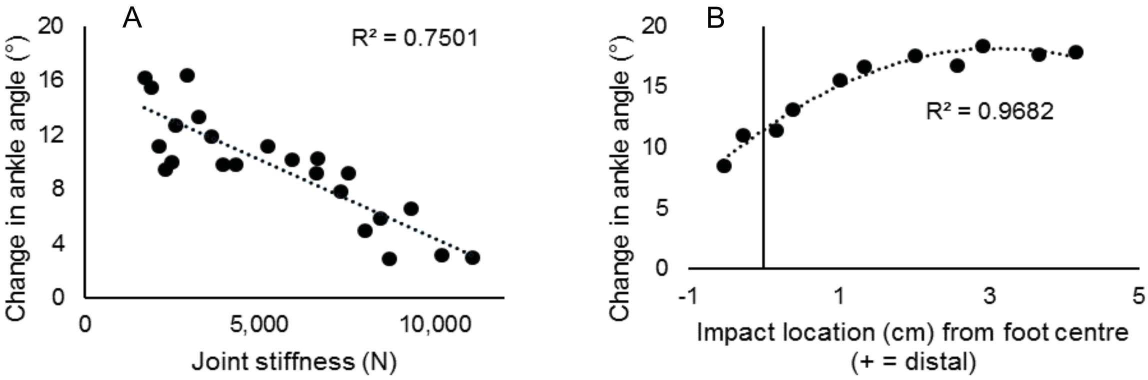

Figure 2. Ankle stiffness and change in ankle scatterplot (A). The dashed line represents a negative linear relationship between the two measures (P < 0.001). Impact location and change in ankle angle (B). The dashed line represents a 2^nd order regression between the two measures (P < 0.001).

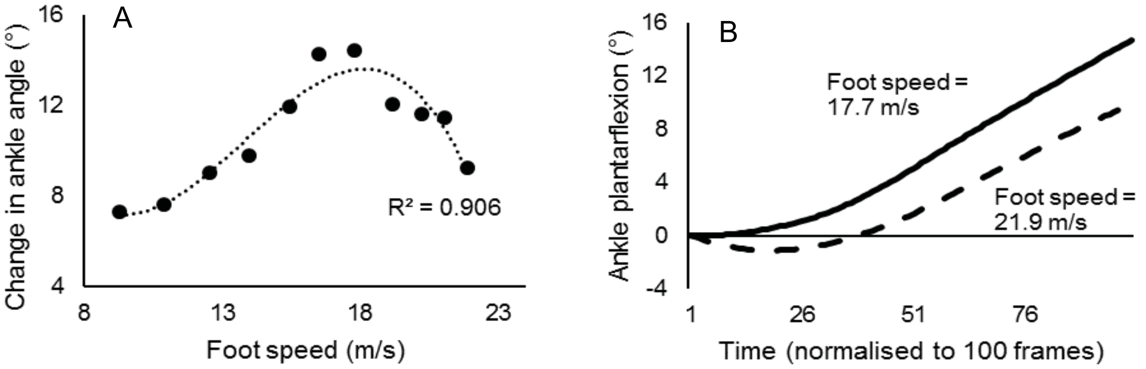

Figure 3. Foot speed and change in ankle angle (A). The dashed line represents a 3^rd order regression between the two measures (P < 0.001). *Post-hoc* analysis in the foot speed data set, comparing the ankle motion of two different speeds.

A second order relationship was identified between impact location along the dorsal aspect of the foot with ankle plantar-flexion, meaning plantar-flexion increased as the impact location moved distally away from the ankle. Interestingly, the increase in plantar-flexion diminished when impacting the ball at a lower point on the foot, most notably identified in the four trials with the most distal impact location. This finding was surprising because it was initially thought plantar-flexion would continually increase as the torque applied about the ankle joint increased, due to the impact location being further away from the ankle joint. *Post-hoc* analysis identified a linear relationship between impact location with contact time, and a linear relationship between the time of phase 4 during ball impact (see 4 individual phases in Shinkai et al., 2009) also with impact location, meaning the total contact time and the time spent in phase 4 of impact increased as impact location moved distally away from the ankle. Further *post-hoc* analysis identified during phase 4 of impact the plantar-flexion velocity decreased and even became negative to indicate dorsiflexion in the four trials with the impact location most distal to foot centre. This meant that as impact location moved distally, the ability to dorsi-flex at the end of impact was increased, leading to a decreased overall plantar-flexion. Peacock et al., (2017) identified during phase 4 of impact that foot speed increased, and suggested elastic energy stored in the anatomical structures around the foot during deformation (phases 1 and 2) was released as the force applied between the foot and ball diminished. The results of this study present a similar mechanism as dorsiflexion occurred in the final phase of impact. However, this only occurred in kicks that underwent severe plantar-flexion, or kicks where a substantial amount of elastic energy was stored in the springs preventing plantar-flexion, indicating a substantial amount of elastic energy must be stored in the deformed ankle to produce a force large enough to accelerate the foot. This reduction in forced plantar-flexion in the four most distal trials however was not considered to increase performance though, because the dorsiflexion occurred during phase 4 of impact when ball velocity did not increase, and rather it might be the ankle motion during phases 1 to 3 that is influential to performance.

A third order polynomial was identified between foot speed and ankle plantar-flexion. The third order relationship was surprising because it is logical to expect plantar-flexion to increase as the torque applied about the ankle increased from the increased foot speed, due to a greater force applied between the foot and ball. However, *post-hoc* analysis identified the five trials with the highest foot speed were dorsiflexion at impact start, which decreased the forced plantar-flexion. Analysing plantar-flexion through the impact phase of instep soccer and drop punt kicking, Shinkai et al., (2009) and Peacock et al., (2017) identified three general patterns of ankle plantar/ dorsiflexion during impact: initial dorsiflexion followed by distinct plantar-flexion; immediate plantar-flexion lasting the duration of impact; and dorsiflexion throughout the entire phase. Of the three patterns, the majority of participants for both kicking types displayed initial dorsiflexion followed by distinct plantar-flexion. Shinkai et al., (2009) suggested impact location and foot orientation were possible factors influential to the corresponding ankle motion, and we identify here that dorsiflexion at the start of impact is another factor that can influence ankle motion, by increasing the momentum of the foot in the opposing direction to the force applied by the ball dorsiflexion at impact start. This highlights another method to reduce the forced plantar-flexion during impact.

CONCLUSION: This study identified the relationship between three impact characteristics (joint stiffness, impact location and foot speed) and ankle plantar-flexion by using a mechanical kicking machine to systematically analyse each factor. Increasing ankle stiffness decreased plantar-flexion, indicating that players with low rigidity should include strength training exercises to reduce the forced plantar-flexion during impact. As the impact location moved distally, plantar-flexion increased, however, the increase in plantar-flexion did plateau. This plateau was caused by dorsiflexion in the final phase of impact, but only occurred in kicks where a substantial amount of elastic energy was stored in the spring mechanism preventing plantar-flexion. A third order relationship was identified between foot speed with plantar-flexion. This relationship was surprising because it was expected plantar-flexion to increase as the force increased from a greater foot speed across the data set. However, *post-hoc* analysis identified that dorsiflexion at the start of impact reduced plantar-flexion, and highlighted another strategy to decrease plantar-flexion during impact: by actively dorsiflexion at the onset of impact.

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