KICK IMPACT FORCES FOR DIFFERENT RUGBY BALL SIZES, IMPACT POINTS AND INFLATIONS

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

Institute of Health, Exercise and Sport (IHES), Victoria University, Footscray, Australia[1]
College of Sport and Exercise Science, Victoria University, Footscray, Australia[2]

The purpose of this study was to evaluate force characteristics of impact during kicking rugby balls of different size and inflation pressures and with different foot-ball contact positions. A mechanical kicking limb struck rugby balls of sizes 3 (smallest), 4 and 5 (used in senior competition). Foot and ball speed, contact time and distance and impact forces were calculated from 2D high speed video (4000 Hz). Overall, average contact force decreased as the ball size decreased. Decreasing inflation pressure also decreased average contact force. Finally, contacting the ball in the middle section produced lower forces than for similar kicks contacting the point of the ball. Manipulating ball size, inflation and contact position provides a platform for progressive kick-specific conditioning.

KEY WORDS: Rugby, high speed video, kick-specific conditioning.

INTRODUCTION: The average force applied to the ball during kicking is large, ranging from 1000 N - 1300 N across the different football codes (Nunome et al., 2014). Conditioning the leg for these impacts is difficult given the nature of the task, with contact time being only one hundredth of a second, and range of motion at the knee being approximately 15 deg/s (Nunome et al., 2014). Further, knee angular velocities of approximately 1500 deg/s have been reported for punt kicking (Ball, 2008a) but even the fastest isokinetic movements rarely exceed 300 deg/s (20% of the kick values). Nunome et al. (2006) identified this as a potential reason why research attempting to explore strength characteristics with kicking performance has been problematic. Given these constraints, manipulation of kicking itself offers the best approach to improving kick-specific strength at impact.

Progressive overload is an important conditioning principle and this might be achieved for kicking impact in a number of ways. Increasing kick length is an obvious one, although players can still kick a ball with a range of force to reach the same distance target (i.e. a 20 m kick can be performed with a minimum of velocity or kicked with high ball speed producing a flat trajectory representing a potentially large force range), so control of loads using this method can be an issue for shorter distances. Altering the mass of the ball being kicked is a simple method to change impact forces. This can be done by using balls of different size or type, or of increasing the mass in some way (e.g. Ball, 2008b, soaking a leather ball in water and as the ball absorbed some of the water it became heavier). Different inflation pressures in the ball might vary loading patterns and represents an easy manipulation to use in training. Finally, anecdotal reports from players indicate a different ‚hardness’ between the point and the middle of rugby and Australia Football (AF) balls which might indicate a difference in force on the ball.

Use of overweight balls has been found to improve kicking distance. Ball (2008b), using balls that were 10-15% heavier than the regular game ball, performed a training intervention over 5 weeks on elite AF players. Players were divided into one of three groups prior to the intervention: a distance kicking group who used weighted balls, a distance kicking group who used regular balls and a control group. Maximum distance kicking was measured both before and after the intervention. Both distance kicking groups improved by approximately 5 m. However, the weighted ball group improved slightly more than the regular ball group. Ball (2008b) suggested that a longer intervention might have seen these improvements become significant between the weighted and normal ball groups.

An easy method of varying mass in balls being kicked, particularly where they are synthetic and won't absorb water like a leather ball, is altering ball size. However, no study has examined impact forces with different sized balls, nor have the impact point or inflation pressure been examined. The aim of this study was to evaluate force characteristics of impact during rugby kicks, manipulating ball size, impact point and inflation rate.

METHODS: A mechanical kicking limb (previously validated, Peacock and Ball, 2017) performed kicks with a standardised foot speed at ball contact of 17 m/s. Four rugby balls (Gilbert) of sizes 3 (smallest), 4 and 5 (full sized ball used in senior rugby games) were fixed with three markers consisting of reflective tape with a circular black dot in the middle. One marker was paced on the seam of the ball near each point and one was placed on the seam in the middle of the ball such that a straight line was made between these markers when viewed from the side. The kick foot itself, a 3D print of a footballer's foot, was fitted with an Adidas football boot. Kicks were performed contacting two impact points on the ball. The first, termed place kick for this study (as this is the position many goalkickers strike the ball) was on the point of the ball while the second, termed drop punt, impacted at a position approximately 1/3 of the way towards the middle of the ball. These were chosen as they represent two common impact points in kicking in the rugby codes. Two pressures were used for all balls for drop punt kicks (10 psi = standard pressure and 5 psi) as well as one ball being progressively deflated to examine the effects of inflation pressure with greater resolution.

A high-speed video camera (HSV) (Photron SA-3, Photron USA Inc., San Diego, USA) placed approximately 6m away from the kick area and perpendicular to the line of kick captured two-dimensional data of the ball, kick foot and kick leg shank during the impact phase of the kick at 4000 Hz. The reflective markers on the ball and kick leg were tracked through impact from 20 frames before to 20 frames after visually identified ball contact and release using ProAnalyst software (Xcitex Inc., Massachusetts, USA) then XY data were transferred to Visual3d software (C-Motion Inc., Maryland, USA) for further analysis.

To evaluate foot and ball speed, the five frames immediately before and immediately after ball contact were used. For force calculations, data from the instant the foot first contacted the ball until the instant the ball left the boot were smoothed using a low-pass 4th order Butterworth digital filter with a cut-off frequency of 150 Hz with six frames reflected at the beginning and end of the signal. Cut-off frequency was initially chosen based on four criteria: residual analysis that indicated a range between 170- 260 Hz (Winter, 2009); the change in parameter values using different cut-off frequencies (240 – 280 Hz with substantial change in parameter values below 200 Hz); visual inspection of data transformation (240 – 300 Hz); and previous literature (200 – 350 Hz) (e.g. Shinkai et al., 2009). However, as a lower frequency was evident in subsequent analyses (approximately 150 and 180 Hz due to a 'ripple' through the ball caused by impact deformation) this was adjusted to 125 Hz

Smoothed displacement data were then used to evaluate time-based and discrete parameters. Displacement data were differentiated to obtain speed (for foot and ball speed) and acceleration with force calculated as the mass of the ball (420 g) multiplied by the acceleration of the ball during impact. To examine force profiles, time-based data for the foot and ball were normalised to 100 frames from the instant of ball contact (0%) until the point of separation of foot and ball (100%). For each, velocity was obtained using the derivative of displacement data. Six discrete parameters were also calculated from the smoothed displacement data and velocity calculations (see Table 1). Between one and three trials were obtained for each ball condition.

RESULTS: Ball size, inflation and impact location all affected impact characteristics (Table 1). Overall, a reduction in ball size reduced average and maximum force, contact time and work while contact distance did not change substantially. A reduction in inflation also saw a decrease in maximum and average force as well as work. However, these changes were larger than those produced by changing ball size. Further, contact time and distance both increased. Comparing impact points, place kicks exhibited greater foot to ball speed ratios, contact times, distances and work indicating that impact location is also influential to impact characteristics in kicking.

Table 1. Impact characteristics for different ball sizes, inflation levels and impact points.

	Foot:Ball Speed Ratio	Contact Time (ms)	Contact Distance (m)	Average Force (N)	Max Force (N)	Work (J)
Size 5 Drop Punt 10 psi	1.25	10.9	0.15	887	2364	132
Size 5 Drop Punt 5 psi	1.21	13.4	0.18	698	1904	124
Size 4 Drop Punt10 psi	1.29	10.6	0.14	768	1962	109
Size 4 Drop Punt 5 psi	1.27	13.0	0.18	592	1582	105
Size 3 Drop Punt10 psi	1.28	10.5	0.14	685	1749	97
Size 3 Drop Punt 5psi	1.25	12.7	0.17	507	1294	85
Size 5 Place Kick10 psi	1.32	11.8	0.17	869	2340	151
Size 4 Place Kick10 psi	1.37	11.8	0.17	707	1887	123
Size 3 Place Kick10 psi	1.38	11.5	0.18	621	1597	110

Place kick = impact point on the point of the ball
Drop punt = impact point /3 of the way from the point to the middle of the ball

Inflation pressure showed a curvilinear relationship with impact force (Figure 1). At 5 psi during a drop punt kick, the average force was approximately 700 N which increased to over 900 N at 11 psi. A more rapid change was evident at the lower ends of inflation pressure.

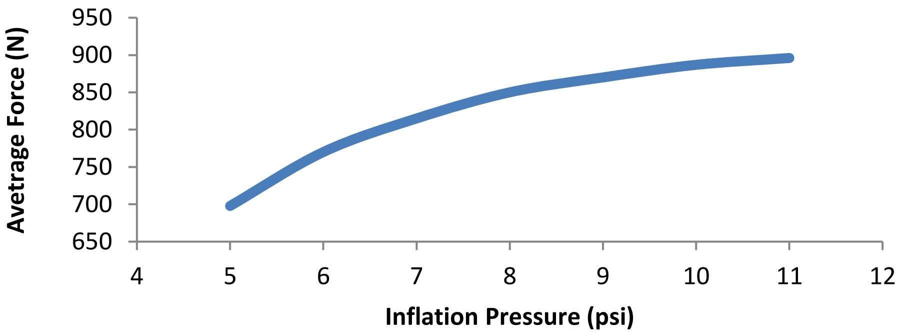

Figure 1: Average force for increasing ball pressure (size 5 ball, drop punt)

DISCUSSION: Ball size, inflation and impact point all affected average force during the kick. The effect for ball size is likely related to the mass of the ball so using F=ma forces are lower. In decending order of force, the size 5 (430 g, heaviest) followed by the size 4 (390 g) and the size 3 (355 g) supported this simple mechanism. The effect for inflation might be related to a longer contact time and distance between foot and ball. As noted in Table 1, and using the size 5 ball to illustrate, there was a 2.5 ms difference (23%) between 5 psi and 10 psi balls. This could be explained by the increased time changing the impulse profile (Impule = Ft) where increasing t means a decrease in F. It might also be explained looking at the work done on the ball (W = Fd) with contact distance increasing so F decreases. Although there was 8 J less work done on the ball for the 5 psi kick, this cannot explain all of the 21% difference in average force. Impact point also affected impact forces with kicks contacting the point of the ball exhibiting higher forces. Michelini et al. (2019) reported finding different coefficients of restitution on the rugby ball with the point of the ball exhibiting a range of 0.5-0.6 compared to the drop punt impact point of 0.4-0.45, supporting this possibility.

Manipulating ball size and inflation can provide a progressive overload for kicking to assist development and rehabilitation when returning from injury. For the conditions tested, average impact forces ranged across approximately 400 N (507 to 887 N, size 3 to size 5, Table 1). Further, there is a progression from the lowest impact force of 507 N to 592 N, 685 N, 698 N, 768 N up to 887 N for drop punt kicks This would be in addition to manipulating the length of the kick as while foot speed was held constant for the purposes of this study, this would also provide a range of impact force characteristics. The 17 m/s foot speed was chosen as it represented an approximate midpoint for foot speeds in our work but these have ranged from 7 to 28 m/s for ovoid ball kicks (data from VIU biomechanics laboratory) so altering distance (ensuring some control on ball flight) can increase the range of forces at impact further. Expanding the inflation pressures further (below 5 or above 11 psi), and using smaller or different balls (e.g. size 2 footballs, tennis balls) will also likely provide a greater range of forces to manipulate in training.

There is a skill factor that needs to be managed in performing this type of training with deflated balls. While under-inflated balls lower forces, contact time increases. This will likely mean greater range of knee extension during impact and will certainly alter rate of force development. This might affect skill development adversely due to the different impact characteristics that will be experienced when using full sized balls. It might also affect the rehabilitation process by providing a force development rate that it lower than what will be experienced once players are kicking full sized/inflated balls again. Variation in training needs to be factored in in any programme and offset with normal pressure kicks (for example using lower inflation size 5 balls and normal inflation size 3 balls).

CONCLUSION: Manipulation of ball size inflation and impact point alters the impact forces and characteristics in kicking. These findings provide a structured progressive overload for conditioning for kicking and for a more structured and earlier re-initiation of kicking into the rehabilitation from injury by providing a kick-specific load progression.

REFERENCES:

Ball, K. (2008a). Biomechanical considerations of distance dicking in Australian rules football. *Sports Biomechanics, 7*, 10-23.

Ball, K. (2008b). Use of weighted balls to increase kick distance. In: *Science and Football VI: The Proceedings of the Sixth World Congress on Science and Football*, Eds: Reilly, T., & Korkusuz, F. Abingdon: Routledge. 36-40.

Michelini, R., Peacock, J., Taylor, S., & Ball, K. (2019). Rugby ball impact point alters the cofficient of restitution and ball speed. *Proceedings of the Ninth World Congress on Science and Football (WCSF2019.com).*

Nunome, H., Ball, K., & Shinkai, H. (2014) Myth and fact of ball impact dynamics in football codes, *Footwear Science*, 6, 105-118

Peacock, J., & Ball, K. (2017). The relationship between foot-ball impact and flight characteristics in punt kicking. *Sports Engineering, 20*, 221-230.

Shinkai, H., Nunome, H., Isokawa, M., & Ikegami, Y. (2009). Ball impact dynamics of instep soccer kicking. *Medicine & Science in Sports & Exercise, 41*, 889-897.

Acknowledgements

The authors would like to thank: Mick Küsel (Küsel Designs) for construction of the mechanical limb.