THE INFLUENCE OF BALL INFLATION PRESSURE ON IMPACT FORCE AND HEAD ACCELERATIONS

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The study investigated the effects of ball inflation pressure on head impact biomechanics. In a two-stage study, footballs with a range of ball inflation pressures (0.4 – 0.95 atm) were impacted into a force plate across a range of ball velocities. Next, 12 male players headed a reduced range of inflation pressures (0.4 & 0.54 atm) and ball velocities (5 & 8m/s) whilst instrumented with three-dimensional motion capture markers to assess linear and angular head accelerations. Results suggest that in isolation, a reduced inflation pressure reduces peak impact force across all velocities barring a low velocity of 4.6 m/s. *In Vivo*, findings suggest that inflation pressure has no effect on linear or angular head accelerations at any velocity, and ball velocity has no effect on linear accelerations. However, a ball velocity of 5 m/s could reduce angular accelerations by 180 rads/s^2 (95% CI: 104 – 255 rads/s^2).

KEYWORDS: Football, heading, ball pressure

INTRODUCTION: Football is the world’s most popular sport, with 265 million participants worldwide (FIFA, 2007). However, there are concerns that football participation, at least at a professional level, increases the risk of neurodegenerative diseases (Mackay et al., 2019; Pupillo et al., 2020). Although not explicitly measured as a causative mechanism, repeated heading of the ball over the course of a career has been proposed as a potential mechanism for this increased risk. This fear prompted many governing bodies – such as the FA, US Soccer and UEFA – to implement safe heading guidance for both youth and professional players in training, largely pertains to the maximum number of headers that should be completed within a training environment. However, while reducing the number of headers completed in training is a viable strategy within youth football, concerns have been raised that heading should still be taught, considering there are no restrictions within matches. Thus, strategies to reduce head impact burden that don’t cause considerable changes to playing dynamics, and that also allow for sufficient training and learning to take place, are needed (Tierney, Power, & Simms, 2020).

Ball inflation pressure is an easily modifiable factor that can influence head impact magnitude (Auger et al., 2020). While the impact magnitude of a header – commonly expressed as either an impact force or linear and angular accelerations of the skull – is mostly influenced by the velocity of the incoming ball, inflation pressure has been seen to significantly influence impact biomechanics. Currently, the FA Laws of the Game state ball inflation pressure must be between 0.6 – 1.1 atm. Auger *et al.,* (2020) observed that reducing ball inflation pressure from 1.1atm to 0.54atm reduced ball impact force by roughly 400N with a ball velocity of 14 – 16 m/s. Similar reductions were observed with ball velocities between 17 and 22 m/s (Cecchi, Monroe, Moscoso, Hicks, & Reinkensmeyer, 2020). However, these ball velocities are much higher than those seen in youth football, where it has been estimated the highest ball velocity during purposeful heading is 15 m/s (Babbs, 2001). They are also considerably higher than those seen in frequently used ‘throw and return’ drills used by youth coaches to introduced heading. Thus, it remains to be seen whether reducing ball inflation pressure, even below FA guidelines, has any marked effect on head impact magnitude at lower ball velocities. The approach to this problem in the currently study was two-fold: firstly, to assess whether reducing inflation pressure reduced ball impact force across a range of velocities used in ‘low impact’ technique drills in isolation, controlling for any confounding variables such as individual player heading technique or anthropometrics (Babbs, 2001). Secondly, to see whether any effects of inflation pressure still remain when tested *in vivo,* by assessing whether reducing inflation pressure reduces linear and angular head accelerations at different velocities in male players.

METHODS: For both stages of study, ethical approval was provided by the local University's ethical committee. In the preliminary stage of the study, a single size 4 football (0.37kg; Mitre Impel Training Ball, Mitre, UK) was impacted into a vertically mounted force platform sampling at 10,000 Hz (Kistler 9281B, Kistler, UK) 50 times each at inflation pressures of 0.4, 0.54, 0.68, 0.81 and 0.95atm. Ball were launched by a single researcher kicked the ball from 3.5m directly in front of the force plate, across a range of velocities. Incoming ball velocity was measuring using three-dimensional motion capture sampling at 1000 Hz (Vicon T40s, Vicon Motion Systems, UK). The ball was fitted with 6 passive reflective markers and model as a spherical segment. Peak resultant impact force was measured as the global maximum force value between the start of impact (first instance of force above 'quiet standing' mean plus 5 * standard deviation of 'quiet standing' (Lake et al., 2018)) until the first instance of force below this same value. Incoming ball velocity was defined as the mean of 20 frames of incoming ball velocity data prior to the start of impact. Statistical analyses were completed using SPSS V23 (IBM, New York, USA). The influence of ball inflation pressure on peak ball impact force was calculated using an analysis of covariate (ANCOVA) model, with incoming ball velocity as a covariate and inflation pressure as a categorical predictor. An interaction term of categorical predictor variable and covariate was also included to assess whether the relationship between covariate and dependent variable was the same across the range of velocities tested. Planned simple contrasts were completed at three levels of the covariate to represent low (4.6m/s; 10% percentile all kicks), medium (9.8m/s; median all kicks) and high (15.54m/s; 90% percentile all kicks) ball velocities, assessing the difference in estimated marginal means between each pressure and a reference category of 6psi (the lowest ball pressure tested), with a significance value of 0.0125, to adjust for multiple comparisons.
For *in vivo* data collection, 12 male participants (age 24 ± 3.2 years; height 178 ± 4.1 cm; mass 82 ± 7.1 kg) were recruited and gave informed consent. Following preliminary results from the first aim, participants were required to head balls at two different velocities and two different inflation pressures. Ball velocities were 5 m/s and 8 m/s to approximately mimic low and medium velocities from stage one of the study. Higher velocities were not used due to laboratory space limiting a consistent incoming speed. Ball inflation pressures were 6psi and 8psi, to mimic the lower end pressures used in stage one. Participants were fed a total of twenty headers (5 in each velocity and pressure condition). For the low-ball velocity, participants were fed a ball underhand from a researcher 4.5m away and asked to return the ball to the researcher's feet. For the higher ball velocity, participants were asked to head a ball dropped from a standardised height (4m above and 4.5m in front of the participants) and asked to return the ball the feet of a researcher 4.5 in front of the participant. Pilot testing showed hand fed ball velocities were consistently within 0.4m/s of the 5m/s target, and dropped ball velocities were consistently 0.1 m/s of the 8m/s target. Peak resultant linear (*g*) and angular (rads/s^2) head accelerations were assessed using three-dimensional motion capture sampling at 1000 Hz (Vicon T40s, Vicon Motion Systems, UK). Participants were fitted with a neoprene skull cap with six passive-reflective markers attached to model the head as a spherical segment. Raw marker trajectories were filtered with a 35Hz low pass Butterworth filter, and head kinematics calculated as per (Austin et al., 2020). Statistical analysis was completed using JASP (JASP Team, USA). Pressure and velocity effects were assessed using a two-way repeated measured ANOVA. If main effects were present, Bonferonni adjusted pairwise comparison's and Cohen's d effect sizes were calculated between inflation pressures and/or ball velocities.

RESULTS: In the first stage of study, the covariate, incoming ball velocity, was significantly related to the ball impact force ($p < 0.001$, *partial* $\eta^2 = 0.974$). There was a significant effect of ball inflation pressure on peak ball impact force after controlling for incoming ball velocity ($p = 0.002$, *partial* $\eta^2 = 0.071$). Planned contrast showed a pressure of 0.4atm did not significantly reduce peak impact force compared to 0.54psi at a low-ball velocity ($p = 0.115$), but did

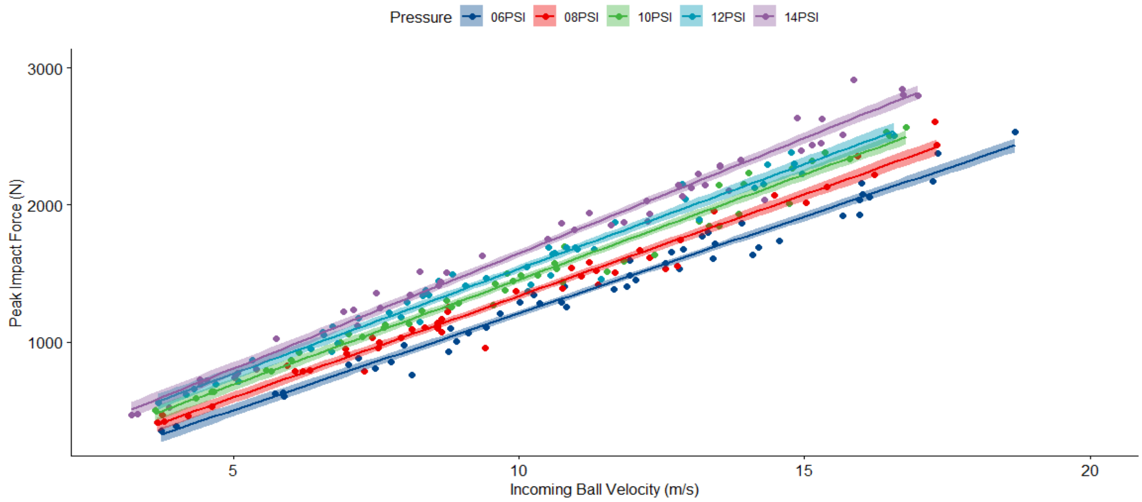

Figure 1. Scattergraph of the covariate (incoming ball velocity) against peak impact force, with separate regression lines (±95% confidence band) for each categorical predictor (inflation pressure).

significantly reduce peak impact force compared to 0.54psi at a medium and high ball velocity ($p < 0.0125$), and compared to 0.68, 0.81 and 0.95atm at all ball velocities ($p < 0.0125$). Figure 1 shows the relationship between the covariate and peak impact force for all ball inflation pressures.

For the second stage of study, there were no interaction effect ($p = 0.38$) or main effect for velocity ($p = 0.229$) or pressure ($p = 0.185$) for linear head accelerations. For angular accelerations, there was no interaction effect ($p = 0.595$) or main pressure effect ($p = 0.168$), but there was a velocity effect ($p < 0.001$). High velocity headers showed an increase of 180 rads/s^2 (95% CI: 104 – 255 rads/s^2) over low velocity headers ($p < 0.001$, $d = 1.5$). Descriptive statistics are presented in table 1.

DISCUSSION: Initial force plate impact data shows that a lower inflation pressure appears to reduce impact force across the range of velocities measures, with the exception of low velocity (4.6m/s). Absolute differences in impact force between inflation pressures appear to be larger at high velocities, although a greater number of observations at these velocities are needed. Observations suggest that at ball speeds of 9.8 m/s or greater, even modest reductions of 2psi below the FA Rules of the Game recommendations could reduce impact force during heading. When observed during football heading, both inflation pressure and ball velocity had no effect on linear head accelerations, reflecting the no difference found a low ball velocities in impact force. This could potentially be due to the low accelerations reported, with an overall group mean of 4.9 ± 1.6 *g,* suggesting a 'lower end' of head accelerations, whereby the incoming velocity is so low that impact biomechanics are unaffected by extraneous ball factors such as inflation pressure.

Although there was no main effect for inflation, there was a main effect for ball velocity in angular accelerations, with a mean difference of 180 rads/s^2 (95% CI: 104 – 255 rads/s^2) between a ball velocity of 5 m/s and 8 m/s. Such a finding is unsurprising given a basic understanding of Newtonian physics ($F = MA$), but it is curious that differences exist for angular

Table 1. Descriptive statistics for study stage 2 linear and angular accelerations for all pressures and velocities.

	Low Pressure (0.4atm)		High Pressure (0.54atm)	
	Linear Acceleration	Angular Acceleration	Linear Acceleration	Angular Acceleration
Low Velocity (5m/s)	4.6 ± 1.4 *g*	420 ± 102 rads/s/s	4.8 ± 1.6 *g*	430 ± 67 rads/s/s
High Velocity (8 m/s)	4.8 ± 1.3 *g*	592 ± 156 rads/s/s	5.4 ± 2 g	620 ± 177 rads/s/s

head accelerations and not linear head accelerations (Babbs, 2001). Given that angular accelerations have been proposed as the primary causative mechanism for axonal injury (Hoshizaki et al., 2017), any strategy to reducing impact should be considered, such as reducing ball velocity in basic heading practice drills by small increments. However, it should be noted that the clinical significance of such reductions is yet to be seen. Furthermore, confirmation of observations within populations such as youth players is needed before practical recommendations are given, as youths have been theorised to produced greater head accelerations than adults due to anthropometric and skill based differences (Babbs, 2017).
A key limitation of the study is the use of three-dimensional motion capture for detecting head accelerations, due to soft tissue artefact (Camomilla, Dumas, & Cappozzo, 2017). The methods used reflect the technologies available to the researchers at the time of study, with data filtering methodologies showing no fixed or proportional bias when compared to a gold standard measure, established through pilot testing.
Practically, findings could suggest that for low velocity football heading drills, such as ‘throw and return’ style activities, ball inflation pressure has little importance with regards to reducing head impact burden. However, it should be noted that the ball inflations and ball velocities investigated for *in vivo* analysis represent a very small band within each respective variable. While it is unlikely that ball inflation would be reduced below 6psi in applied coaching scenarios due to inferred effects on playing dynamics and reduce ‘bounce’, balls may be arbitrarily inflated above the 8psi pressure tested if correct pressure monitoring equipment is not used.

Conclusion: The present study provides evidence that lowering ball inflation pressure has the potential to reduce peak impact force in isolation, when impacted against a static force plate. Altering inflation pressure across a range of pressures legal within the FA Laws of the Game could potentially alter impact force to a large degree. However, when viewed *in vivo*, modest reductions in inflation pressure below those legal within the FA Laws of Game has no effect on linear or angular accelerations at low ball velocities.

REFERENCES

Auger, J., Markel, J., Pecoski, D. D., Leiva-Molano, N., Talavage, T. M., Leverenz, L., … Nauman, E. A. (2020). Factors affecting peak impact force during soccer headers and implications for the mitigation of head injuries. *PLoS ONE*, *15*(10 October 2020), 1–15. https://doi.org/10.1371/journal.pone.0240162

Austin, K., Lee, B. J., Flood, T. R., Toombs, J., Borisova, M., Lauder, M., … Smith, N. a. (2020). Serum neurofilament light concentration does not increase following exposure to low velocity football heading. *Science and Medicine in Football*, *00*(00), 1–7. https://doi.org/10.1080/24733938.2020.1853210

Babbs, C. F. (2001). Biomechanics of Heading a Soccer Ball: Implications for Player Safety. *The Scientific World*, *1*, 281–322. https://doi.org/10.1100/tsw.2001.56

Babbs, C. F. (2017). *Increased Risk of Children for Subtle Closed Head Injury From Soccer Heading Increased Risk of Children For Subtle Closed Head Injury*.

Camomilla, V., Dumas, R., & Cappozzo, A. (2017). Human movement analysis: The soft tissue artefact issue. *Journal of Biomechanics*, *62*, pp-1.

Cecchi, N. J., Monroe, D. C., Moscoso, W. X., Hicks, J. W., & Reinkensmeyer, D. J. (2020). Effects of soccer ball inflation pressure and velocity on peak linear and rotational accelerations of ball-to-head impacts. *Sports Engineering*, *23*(1), 12–17. https://doi.org/10.1007/s12283-020-00331-0

Hoshizaki, T. B., Post, A., Kendall, M., Cournoyer, J., Rousseau, P., Gilchrist, M. D., … Marshall, S. (2017). The development of a threshold curve for the understanding of concussion in sport. *Trauma (United Kingdom)*, *19*(3), 196–206. https://doi.org/10.1177/1460408616676503

Lake, J. P., Mundy, P. D., Comfort, P., McMahon, J. J., Suchomel, T. J., & Carden, P. (2018). The effect of barbell load on vertical jump landing force-time characteristics. *Journal of Strength and Conditioning Research*, 1. https://doi.org/10.1519/jsc.0000000000002554

Mackay, D. F., Russell, E. R., Stewart, K., MacLean, J. A., Pell, J. P., & Stewart, W. (2019). Neurodegenerative Disease Mortality among Former Professional Soccer Players. *The New England Journal of Medicine*, 1–8. https://doi.org/10.1056/NEJMoa1908483

Pupillo, E., Bianchi, E., Vanacore, N., Montalto, C., Ricca, G., Robustelli Della Cuna, F. S., … Beghi, E. (2020). Increased risk and early onset of ALS in professional players from Italian Soccer Teams. *Amyotrophic Lateral Sclerosis and Frontotemporal Degeneration*, *0*(0), 1–7. https://doi.org/10.1080/21678421.2020.1752250

Tierney, G. J., Power, J., & Simms, C. (2020). Force experienced by the head during heading is influenced more by speed than the mechanical properties of the football. *Scandinavian Journal of Medicine and Science in Sports*, (July), 1–8. https://doi.org/10.1111/sms.13816