ACCELERATION DERIVED FROM INSTRUMENTED MOUTHGUARDS DURING HEADING IN WOMEN'S SOCCER WITH REGULAR AND 'LIGHT' SOCCER BALLS

Levi Bentley[1], Mike Lauder[1] & Neal Smith[1]

University of Chichester, UK[1]

This study investigated the specific types of header that occur in elite women's football (Bentley et al., 2022). Launch speed and angle were replicated in laboratory conditions. An intervention of reduced ball mass (0.29kg v's 0.41kg) was investigated. Common headers were categorised as a) slow controlling header; b) from a throw-in; c) from long-pass/cross; d) from goal kick. A custom fit Instrumented Mouthguard (Prevent Biometrics) sampled at 3200Hz to gain linear and angular accelerations of the skull. Seven female players performed 3 trials of each header, with kinematics also recorded at 1000Hz using 10 Vicon cameras. For the 'light' ball intervention, peak linear velocity of the head was significantly ($p<0.05$) reduced at all ball speeds. If 'light' ball 'playability' can be demonstrated, this could be a useful intervention to mitigate excessive, cumulative head impacts in female football.
KEYWORDS: football, heading, female, mouthguard, ball.

INTRODUCTION: Football (Soccer) is the most participated sport in the world with approximately 265 million players (FIFA, 2007). In 2019, there were more than 13 million women and girls playing competitive football (FIFA, 2019), with female football popularity increasing greatly in recent years with live match attendance increasing 106%, from 8.4 million in 2015 to 17.27 million in 2019 (FIFA, 2019).

Football is unique compared with other contact sports in which players use their unprotected heads to pass, shoot, direct and control the ball. Correlations from large scale retrospective studies have postulated potential adverse effects of purposeful heading have been discussed in literature (Mackay et al., 2019), with some governing bodies, such as the English FA and US Soccer, employing the 'precautionary principle' by banning/limiting heading within certain groups of players.

Structurally, male and female brains display differences and previous research has shown women exhibit more widespread evidence of microstructural white matter alteration, when exposed to similar bouts of heading, than men do (Rubin et al., 2018). Females also exhibit higher head accelerations when heading the ball than their male counterparts (Saunders et al., 2020). Therefore, it seems viable that interventions to reduce skull impact magnitudes may be more relevant to the female game. Possible mitigation of excessive head accelerations have been demonstrated by increasing neck musculature strength (Peek et al., 2020), yet few interventions have investigated the effects of reducing ball mass, especially for female soccer players.

Selection of appropriate measurement devices to record the magnitude of head impacts is also a key decision, as skin mounted markers typically used in motion capture would need to be modelled to calculate the centre of mass of the head (indicative of brain location), or any wearable sensor would need the translation and rotation of accelerometer and gyroscopic data to the centre of mass of the head also. These measurements are possible with an instrumented mouthguard (iMG), which have shown to be accurate by Liu et al. (2020) who conducted laboratory-based impact testing on a crash test dummy headform (gold standard) to assess the accuracy of a range of iMG. Mean relative error scores of 4.9%, 4.6% and 2.5% for peak angular acceleration, angular velocity, and linear acceleration, respectively have been demonstrated using this technique.

The purpose of the study was to analyse the magnitude of head impact in women's football from a range of heading techniques commonly performed in a competitive game scenario, so that typical cumulative 'load' can be estimated. Linear and angular accelerations were examined both (i) with a standard mass soccer ball (0.41 kg), and (ii) a 'light' commercially available soccer ball (0.29 kg) of the same dimensions.

METHODS: Participants: Seven collegiate level football players were recruited (Age 20.9+/-0.4 yrs, Height 166.3 +/-9.1 cm, Mass 69.2 +/- 11.2 kg). Players wore standard indoor footwear, and shorts along with a sports bra only on the torso to enable attachment of markers.
Equipment: Participants had custom fitted instrumented mouthguards (iMG) (Prevent Biometrics, Minneapolis, USA) which were fitted with an accelerometer and gyroscope both sampling at 3200 Hz, with measurement ranges of ±200 g and ±35 rad/s, respectively. An infrared proximity sensor embedded in the iMG was utilised to assess if the iMG was coupled tightly to the upper dentition during the header. The reliability and validity of the Prevent Biometrics custom-fit iMG has been demonstrated in previous studies. Participant motion was captured simultaneously by 10 Vicon T-Series cameras sampling at 1000 Hz, with markers placed on the torso (6) and head (6). Motion capture marker data was modelled and treated in Visual 3D (C-Motion, USA) using a fourth-order, dual-pass Butterworth low-pass filter (cut-off frequency = 18 Hz). The Prevent Biometrics custom-fit iMG recorded Head Acceleration Events (HAE) kinematics when accelerometer measures exceeded 5 g on a single axis of the iMG, capturing 10 ms of pre-trigger data and 40 ms of post-trigger data. The level of noise was classified by an in-house Prevent Biometrics machine learning model which determined whether each HAE contained minimal noise (class 0), moderate noise (class 1) or severe noise (class 2). A 4-pole, zero phase, low-pass Butterworth filter was applied at cut-off frequencies of 200 Hz for class 0 HAE, 100 Hz for class 1 HAE and 50 Hz for class 2 HAE. In-house Prevent Biometrics algorithms transformed linear kinematics to the head centre of gravity (CG). Only impacts determined to be true positives (exceeded 5 g, and involved heading the soccer ball) as per the impact detection algorithm were considered in the analysis. Two ball conditions (size 5) were used Regular (Mitre, Impel L30P, mass 0.41 kg), and Light (Puma, Teamfinal 21 Light, mass 0.29 kg) with participants instructed to perform 3 repetitions under each of four conditions (selected from Table 1) with each ball. The first two conditions were fed by hand to simulate a) slow, controlling header (approx. 5±0.3 m/s) b) header from a throw-in (approx. 6±0.4 m/s); then using a ball firing machine (Soccer Pro Trainer, Sports Tutor, CA, USA) to simulate the velocity of c) a long pass/cross (approx. 11±1.2 m/s) and d) from a goal kick (approx. 14±1.1 m/s). Ball velocities recorded from mean ball marker trajectories in Vicon Nexus (v2.12), with successful headers contacting around the hairline, and the ball trajectory returning back towards the ball firing machine, or feeder.

Table 1: Characterisation of Headers from Match Play (Bentley, 2022)

Header Characteristic	Definition
Attacking	Headed shot on goal
Clearance	Defensive action where a player heads the ball away from her own goal with no intended recipient. Maximum effort and distance.
Cushioned	Takes momentum out of the ball to bring it under control.
Flick On	Player heads the ball in the same direction it was received.
Interception	Player is at full stretch with little head movement.
Pass	Submaximal directional header towards an intended recipient.
Unintentional	Ball hits player’s head unknowingly.

Head kinematics from the iMG were averaged for three repetitions, with mean values then compared with a Paired-samples t-test following Shapiro-Wilks normality checks in JASP,(Version 17, JASP, Amsterdam). Statistical significance was set at $P<0.05$.

RESULTS/DISCUSSION: The purpose of this study was to examine the head accelerations in women’s football and developing intervention strategies (ball mass) to mitigate injury risk from head impacts. For the findings an Asterix (*) indicated $p<0.05$. (vel = velocity; acc = acceleration; Ang = angular).
It should be noted there was no significant difference in ball speed between ‘normal’ and ‘light’ ball for any of the conditions ($p>0.05$) therefore ball impact speed was consistent.

Table 2: Kinematic values for underarm fed control headers

	Peak Linear acc (g)	Peak Ang acc (rad/s^2)	Peak linear vel (m/s)	Peak Ang vel (rad/s)
Regular Ball	10.3	519	0.71	2.8
'Light' Ball'	8.9	409	0.60*	2.0*

From basic underarm feeds for ball control (Table 2), the 'light' ball condition displayed statistically reduced values for linear (p=0.03) and angular (p=0.006) velocity measures. Such results might well be relevant to basic training drills, and very short ranged cushioned headers in a game scenario.

Table 3: Kinematic values for 'throw-in' headers

	Peak Linear acc (g)	Peak Ang acc (rad/s^2)	Peak linear vel (m/s)	Peak Ang vel (rad/s)
Regular Ball	11.2	484	0.77	3.0
'Light' Ball'	10.7	505	0.70*	2.7

A trend of reduced head accelerations and significantly lower linear (p=0.02) velocities were seen in Table 3 with the 'light' football from the most common action of heading from a 'throw-in'

Table 4: Kinematic values for 'long pass/cross'

	Peak Linear acc (g)	Peak Ang acc (rad/s^2)	Peak linear vel (m/s)	Peak Ang vel (rad/s)
Regular Ball	14.7	640	1.00	5.5
'Light' Ball'	13.7	750	0.80*	4.7

Similar trends are once again evident in the higher ball velocity headers (Tables 4 and 5). It may be worth noting that one specific participant outlier may have contributed to the equality of these values, as unfortunately she could only complete one header at this velocity, and the head velocity and acceleration values were markedly larger than other players. Once again linear head velocity was significantly (p= 0.004) lower for the 'light' ball condition.

Table 5: Kinematic values for 'goal kick'

	Peak Linear acc (g)	Peak Ang acc (rad/s^2)	Peak linear vel (m/s)	Peak Ang vel (rad/s)
Regular Ball	22.8	1364	1.21	6.5
'Light' Ball'	16.6	995	0.93*	6.7

The lighter ball again produced overall lower values and significantly lower linear velocities (p=0.002). Fluctuations are worth considering as these values are raw kinematic values, without any relation to perceived 'quality' or 'consistency' of technique. In short, differing locations of head impact will increase the moment arm for angular kinematics, and also have an effect on linear kinematics too. Opportunist sampling of one full female soccer team meant that sample sizes were limited. These headers are directly implied from those performed in a competitive game, whereas the lower velocity headers may be occurring more frequently during training sessions. In future, increased changes to the angular kinematics of the head may occur if the task involves re-directing the ball during the header.

Most headers in training tend to be performed during first touch training where the ball travels at a relatively low velocity, under 5 meters of distance before a cushioned pass back to teammate. Kenny et al., (2022) found similar results in which underhand throw delivery to header was most prevalent phase of play in university women's football training. Overall, values here comply with data from linear and rotational impact kinematics in U14 to U16 female youths for headed goals (27.35g and 1202 rad/s^{-2}, respectively), followed by headers from corners (22.9 g and 1447 rad/s^{-2}; Harriss et al., 2019).

CONCLUSION: The current study demonstrates that a basic intervention of reducing ball mass will give a lower linear kinematic heading load during female soccer play. Results are consistent across ball velocities, yet interpretation of the efficacy of the intervention would require some estimate of 'playability' of the reduced mass ball so that player enjoyment, and possibly crowd entertainment were not also compromised. To give these data greater credibility, a 'playability' study will also need to be conducted to assess qualitative interpretations of the 'light' ball condition, yet initial qualitative measurements show positive results for player welfare. iMG provided a useful baseline data set under controlled laboratory conditions to objectively interpret the effects of reducing heading impact in female soccer players. Once game play factors have been elucidated, it is proposed that a competitive trial of this intervention should be implemented.

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